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Vol. XIII, Part IV

(August 1943)

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ORIGINAL ARTICLES

GROWTH AND YIELD STUDIES ON IRRIGATED PADDY IN UPPER BURMA

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(Received for publication on 30 December 1941)

(With six text-figures)

Any attempt to analyse the factors which contribute to the yield of a cereal crop must commence with a detailed study of the development of the plant, especially the formation and survival of tillers. The work of Engledow *et al.* on wheat and barley at Cambridge has laid the foundation of this type of study. Summers [1921] published results of studies on the tillering of paddy in Ceylon, in which he compared the root development and tillering of broadcast and transplanted paddy, recording that in transplanted paddy the number of panicles produced is greater, tillering more regular and root development greater. Joshi and Gadkari [1923] studied the growth of paddy as affected by environment in Bombay and Bhide and Bhalerao [1927] related growth to height of plant. Correlation studies between characters in rice have been reported by Jacobson [1916] and Vibar [1921] in the Philippines and by Rao [1937] in Madras. Ramiah and Narasimham [1936] studied the growth and tillering of paddy in Madras. We are in general agreement with the results reported by Grant [1935] and by Grant and Thein Aung [1941] for Lower Burma paddy. We have attempted to trace the course of growth and tillering at different spacings, to ascertain the fate of the tillers of different orders and to discover the contribution of each towards the final yield. That it is not necessarily the late-formed tillers which succumb prematurely but that the primary stem may suffer early death is clearly brought out. The relationship between height of seedling at transplanting and subsequent growth has been studied.

Conditions of the experiments

The present experiments were carried out at Mandalay in Upper Burma with irrigated paddy. The annual rainfall is about 33 in. and the soil a heavy black carbonate solonschak clay of *p*H 8. Under normal conditions nurseries are sown about the middle of June and the paddy is transplanted 35 to 40 days later in groups of four to seven seedlings about 10 in. apart. This method of planting is referred to as *htonsan*. Since *htonsan* planting prevents a study of the tillering of individual plants most of these experiments have been done with single seedlings at fixed spacings, though some have been done with *htonsan* planting. Because much of the counting of tillers was done by fieldmen it was considered safer not to enter the numbers of tillers (i.e. number of culms less one) in the records which consequently show the total number of stems. To avoid re-writing voluminous data analysis has in most cases been done on total culm numbers and not on tiller numbers.

Newly transplanted paddy, especially when single seedlings are planted, is much damaged by the land crab *Potamon dayanum* Wood-Mason. Wherever plants are cut by crabs the neighbouring plants benefit by the extra space and respond by more tillering, necessitating the rejection of all plants adjacent to gaps from most of the tillering records. In the 1932 experiments the mean number of tillers for all varieties and treatments was 11·15 for plants adjacent to gaps against 10·32 for those not so placed, a difference of 0·83 ($P > 0{\cdot}01$). Wherever necessary plants so benefited have been disregarded.

Crude tillering curves

An experiment was laid down in 1932 using four varieties, the planting being with single seedlings at 1 ft. × 1 ft. spacing from the same nursery raised under closely similar conditions. The outside and end rows were neglected as well as all plants adjacent to gaps caused by crabs. Cultivation and irrigation were in accordance with the normal local practice. Table I gives the mean stem numbers of approximately 500 plants for each variety at each count.

Table I

Mean stem numbers of four varieties of paddy, 1932

Date of count	Days from transplanting	Ngakyi C406	Ngasein C401	Taung-deikpan B401	Paung-malaung C410
11-8-32	0	1·00	1·00	1·00	1·00
2-9-32	22	4·58	3·55	4·69	3·82
12-9-32	32	12·84	7·94	11·54	11·75
22-9-32	42	18·44	13·63	14·29	15·99
3-10-32	53	19·63	15·02	14·75	16·44
13-10-32	63	19·98	15·46	15·22	16·38
23-10-32	73	19·42	15·06	14·76	15·56
2-11-32	82	16·76	13·15	12·46	13·96
12-11-32	92	13·69	10·13	11·03	Ripe
22-11-32	102	13·28	9·87	Ripe	..

In Fig. 1 the curves of tiller numbers are shown. There is a period of recovery from transplanting followed by a rapid rise in tiller numbers until a

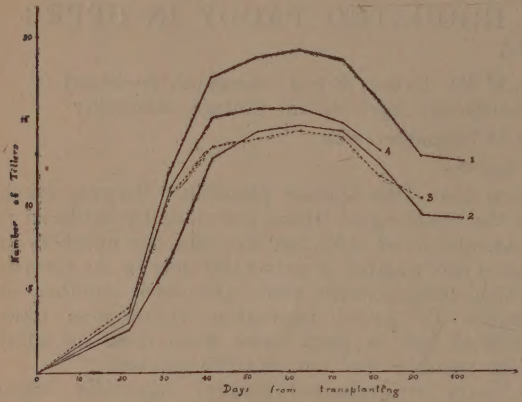

FIG. 1. Tiller numbers of 1. Ngakyi, 2. Ngasein, 3. Taungdeikpan, and 4. Paungmalaung

maximum is reached in about 63 days from transplanting. Thereafter there is a decline due to deaths of tillers until the plants ripen. Mitra and Ganguli [1932] found that the maximum number of tillers was formed about the 7th or 8th week after transplanting. In the present experiments the period of maximum tillering appears to be about the 9th week. The losses of tillers range from 27·5 to 36·1 per cent for the long-lived varieties Ngakyi, Ngasein and Taungdeikpan, while the early Paungmalaung suffered only 15·1 per cent loss. These losses are of a similar order to those recorded by Grant [1941] and Ramiah [1936]. Doughty and Engledow [1928] have formulated the idea of a critical period, a date after which any tillers formed fail to mature. From the above data it would appear that the critical periods for these four varieties would be approximately :

	Days after transplanting	Date
Ngakyi (C406)	33	13-9-32
Ngasein (C401)	35	15-9-32
Taungdeikpan (B401) . . .	31	11-9-32
Paungmalaung (C410) . . .	37	17-9-32

Later experiments have shown that it is incorrect to assume that all tillers formed after these dates are doomed to failure. The critical dates as determined from the crude tillering curve average about 33 days from transplanting, and as there is a period of about 10 to 15 days after transplanting while the plants are recovering from the damage of uprooting there would remain only about three weeks for tiller formation. Actually the case is more complicated and if there is a critical period it does not occur till much later.

In 1933, experiments were done in which a number of plants were selected at random from plots planted at two spacings and tiller counts were made on these selected plants, each tiller being marked with a small label at the time it was first recorded, thus enabling a complete history of each stem to be made from the recording date onwards. Twelve plants were selected at random from a population of 500 of each of two varieties spaced 1 ft. × 1 ft. and 2 ft. × 2 ft. (Appendix Tables I to IV).

The figures are somewhat irregular due to the small numbers of plants counted but the effect of spacing on the numbers of tillers formed is very marked, and also the difference between the varieties.

Fig. 2 shows the actual numbers of tillers formed and died on each recording date. In Taungdeikpan tillering begins about a fortnight after transplanting. At the 1 ft.×1 ft. spacing the maximum rate is quickly reached after which there is a fairly steady decline until by the beginning of November only occasional tillers are formed. At the 2 ft.×2 ft. spacing the tillering rate is very irregular, periods of active tiller formation seeming to alternate with periods of lessened activity, but there is a similar general decline to that shown at the closer spacing. Tiller deaths commence about 4 October at the closer spacing and are first recorded 10 days later at the wider spacing. At the closer spacing there are two modes for the death rate at 19 October and 10 November but at the wider spacing there is only one peak at 2 November. It seems probable, from a consideration of the other curves, that the mode at 10 November was fortuitous.

Ngasein follows the same general course as Taungdeikpan, the rate of tillering at the 1 ft.×1ft. spacing steadily declining after the initial high rate is reached while the rate at the wider spacing shows great irregularity but a general decline. The death rates correspond closely with those of Taungdeikpan showing modes on 19 and 26 November. In general the time of greatest tiller mortality falls between the middle and third week of November.

It is noteworthy that the irregularities shown by both varieties at the wider spacing correspond closely. If the rainfall in summed ten-day totals is plotted, it is seen (Fig. 3) that there are three modes corresponding to the tillering modes of the 2 ft. × 2 ft. spacing (where presumably space was not a limiting factor) but displaced to the left by about 15 days. Such a lag in the effect of rain would be expected. It may at first seem anomalous that rain should have a large influence on an abundantly irrigated paddy crop but there is not only the actual precipitation involved but the beneficial effects of cooling and the lowering of the transpiration rate to be considered. The

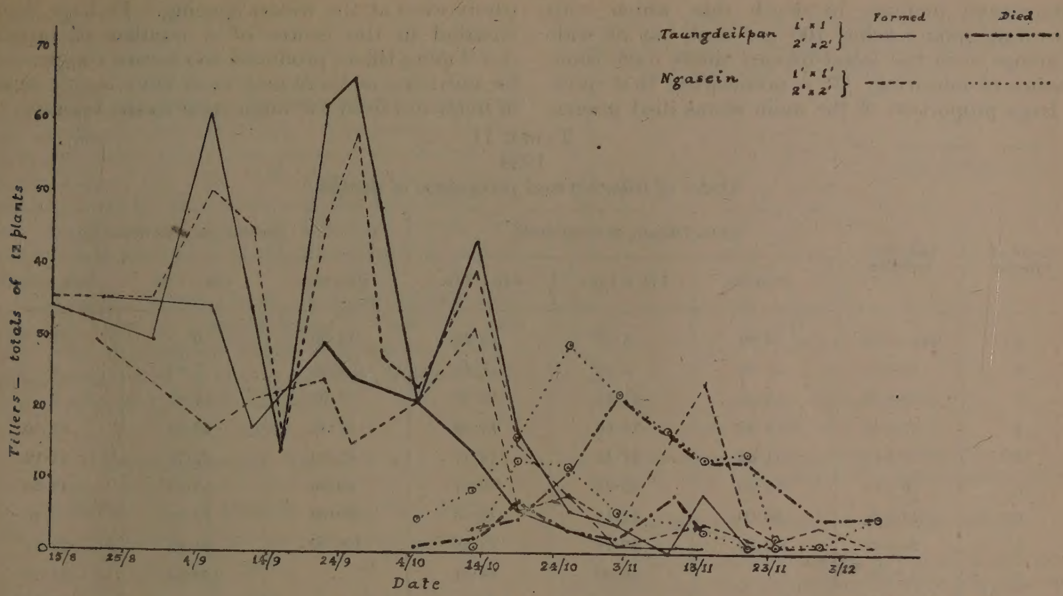

FIG. 2. Actual number of tillers formed and died on each recording date for 1. Taungdeikpan, and 2. Ngasein, in 1933

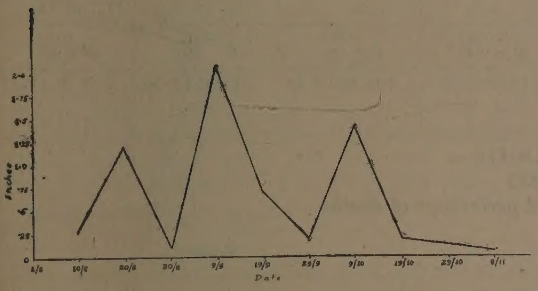

FIG. 3. Rainfall at Mandalay in ten-day periods in 1933

cultivator's belief in the advantages of rain over irrigation water is undoubtedly well founded.

In 1934 this experiment was repeated with group planting (*htonsan*) added and records of the dates of formation of tillers were begun earlier (Appendix, Tables V to X). Although differing in details the general course of tillering is similar to that in 1933. The closer the spacing the earlier and more sharply does the rate of tiller formation decline while concomitantly deaths begin earlier

In this season two modes for rate of tillering are shown by the 2 ft. × 2 ft. spacing against three modes in 1933. Examination of the rainfall shows three modes but the last heavy rainfall period ended on 19 October and was probably too late to stimulate tillering. This was 10 days later than the third rainfall mode in 1933.

Although the periods of rainfall and tillering activity seem to show some correspondence after allowing for about a fortnight's lag, the agreement is not exact. Rainfall alone is not a safe guide to growing conditions since cloudy cool days without any, or with very little, precipitation may be equally effective while, as the season advances and the plant's ability to respond decreases, the influence of rainfall and other climatic factors will decline.

1933			1934		
Tillering modes	Rainfall modes (end dates)	Difference days	Tillering modes	Rainfall modes (end dates)	Difference days
6 Sept.	20 Aug.	17	3 Sept.	20 Aug.	14
26 Sept.	9 Sept.	13	17 Sept.	19 Sept.	2
12 Oct.	9 Oct.	3	..	19 Oct.	..

ORDER OF TILLERING AND TILLER DEATHS

The detailed records of individual tillers made in 1934 and 1935 enable the fate of each tiller to be traced (Tables II and III). In the case of *htonsan* planting the whole group of seedlings has been treated as one unit, and the individuals not separately recorded. While there is a good deal of irregularity (probably due to small numbers) the figures show that there are no distinct periods of tiller formation and tiller death, but that loss of tillers commences early before the maximum number is attained and that formation and loss of tillers proceed concurrently. Ther tend to be a

progressive increase in death rate which with crowding soon reaches 100 per cent but at wide spacings even the latest-formed tillers have some chance of maturing. It is noteworthy that quite a large proportion of the main stems died prematurely even at the widest spacing. Perhaps being situated in the centre of a number of rapidly developing tillers produced too severe competition for nutrients or there may even have been a drain of nutrients from the main stem to the laterals.

TABLE II

1934

Order of tillering and percentage of deaths

Order of tillering	Date first recorded	Taungdeikpan, per cent death			Ngasein, per cent death		
		Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
1	Main stem	20·00	8·33	16·66	12·50	0	25
2	13-8-34	16·66	3·93	7·14	5·55	7·14	0
3	20-8-34	18·75	11·84	13·50	19·05	14·28	8
4	27-8-34	76·92	19·60	16·66	69·76	18·18	21·90
5	3-9-34	41·66	27·44	19·17	87·10	27·78	21·13
6	10-9-34	55·55	33·33	20·37	90·90	58·33	17·65
7	17-9-34	50·00	57·14	16·66	100·00	57·69	9·46
8	24-9-34	100·00	57·14	23·59	100·00	91·66	29·17
9	1-10-34	..	50·00	24·61	..	100·00	37·78
10	8-10-34	..	..	26·31	..	..	61·36
11	15-10-34	..	..	..	..	..	42·50
12	22-10-34	..	..	..	..	..	57·14
Relation between order of tillering and death rate	Correlation Coefficient . .	+·78 P ·05	+·94 P ·01	+·84 $P < ·01$	+·93 $P < ·01$	+·97 P ·01	+·87 $P < ·01$
	Regression coefficient . .	+9·55±3·11	+7·18±0·96	+1·58±·36	+15·69±2·48	+13·01±1·30	+4·21±0·77

TABLE III

1935

Order of tillering and percentage of deaths

Order of tillering	Date first recorded	Taungdeikpan			Ngasein		
		Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
1	Main stem	20·59	16·66	0	33·33	16·66	8·33
2	26-8-35	19·45	13·79	40·00	40·74	18·75	12·00
3	2-9-35	47·62	14·81	10·53	47·62	7·69	6·25
4	9-9-35	50·00	15·62	20·83	77·77	28·57	6·66
5	16-9-35	None formed	34·48	17·50	85·71	11·11	12·12
6	23-9-35	50·00	25·00	31·71	75·00	63·63	5·88
7	30-9-35	33·33	75·00	23·53	None formed	83·33	11·63
8	7-10-35	..	100·00	27·45	100·00	45·45	8·69
9	14-10-35	..	..	12·50	100·00	100·00	29·79
10	21-10-35	..	..	46·15	..	..	45·83
11	28-10-35	..	..	..	..	..	66·66
Relation between order of tillering and death rate	Correlation Coefficient . .	+·53 $P < ·1$	+·84 $P < ·01$	+·43 $P < ·1$	+·94 $P < ·01$	+·81 P ·01	+·78 $P < ·01$
	Regression coefficient . .	+3·30±2·64	+11·18±2·97	+2·00±1·47	+8·77±1·37	+10·00±2·69	+4·54±1·31

In Tables II and III the correlation and regression coefficients between the order of tiller formation and the death rates are given. Except for the 1935 Taungdeikpan closest and widest spacings all values of r are very high. The reason for the low values of r in *htonsan* planting is not clear but in the case of the 2 ft. × 2 ft. spacing there was an unusual loss of 40 per cent of the first tillers for an unapparent reason. If this high death rate for the first tillers is omitted, $r = +0 \cdot 74$, $P > 0 \cdot 01$ and $b = 3 \cdot 35 \pm 1 \cdot 17$.

The greater liability of tillers to die in the variety Ngasein than in Taungdeikpan is clear and also the very pronounced effect of spacing. This is also brought out by the numbers of tillers surviving to maturity, which average.

1934

(From Appendix Tables V to X)

Spacing	2 ft. × 2 ft.	1 ft. × 1 ft.	*Htonsan*
Taungdeikpan . .	23·9	15·7	8·7
Ngasein . . .	30·6	12·7	9·8

Fig. 4 of the regression lines for order of tillering and death rates in 1934 clearly shows the effect of spacing. The regression lines for the 1935 experiments are similar. It is probable that the relationship is not exactly represented by a straight line but the data do not warrant fitting polynomials. Only in the case of group planting do these regressions reach 100 per cent mortality whereas in the field the 1 ft. × 1 ft. spacing is restrictive enough to induce cent per cent deaths of late-formed tillers. At the widest spacing growth is terminated by flowering and drying of the soil before space becomes a limiting factor.

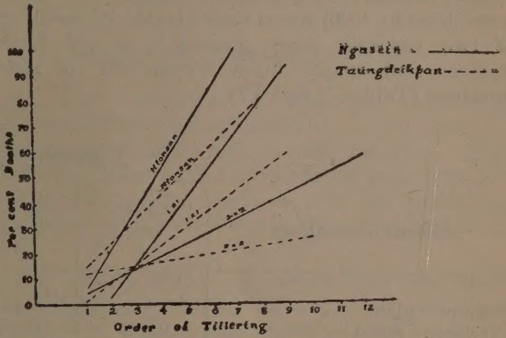

FIG. 4. Regression lines of order of tiller formation and death rates for Ngasein and Taungdeikpan in 1934

HEIGHT OF SEEDLING AND TILLERING

In 1932 the seedlings were not graded according to height and the experiments were planted with seedlings of mixed heights but of the same age. In any nursery, however carefully prepared, quite large differences in height and dry weight occur within the seedling population, probably due to spacing and fertility differences which cannot be avoided. The first records of height were made the day after transplanting and from these a rough classification into height groups was made. The seedling heights are compared in Table IV with the tillers formed 22 and 102 days from transplanting.

TABLE IV

Mean number of stems 22 and 102 days after transplanting (1932)

Height of seedlings (in cm.)	Ngakyi		Ngasein		Taungdeikpan		Paungmalaung	
	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting	22 days from transplanting	102 days from transplanting
30—35 . . .	2·91	12·90	..	..	3·10	9·50	2·40	12·91
35—40 . . .	3·29	13·49	2·37	9·39	3·94	9·78	2·91	12·79
40—45 . . .	3·56	13·00	3·12	9·33	4·95	10·28	2·71	12·98
45—50 . . .	3·38	12·85	2·89	10·02	..	11·68	2·50	12·20
50—55 . . .	3·41	11·05	2·35	8·46	..	..	..	..
55—60 . . .	.	..	1·73	7·54	..	..	..	..
60 and over . .	.	..	1·71	6·22	..	..	..	..

In general, seedlings of medium height gave the largest number of tillers except for Taungdeikpan, but in that variety there were no tall seedlings.

More detailed experiments on height of seedlings were done in 1933 when four lengths of seedlings of two varieties were planted in 4 × 4 Latin squares and counts made fortnightly of stem numbers (Tables V and VI).

In both varieties the shortest seedlings have given the highest numbers of mature stems. The detailed records show that the taller seedlings tillered more rapidly than the shorter in the early stages but that the latter surpassed the former before the maximum tiller number was reached. Height of seedlings is therefore not a sure guide to vigour.

TABLE V

Ngasein—final stem numbers

Height of seedlings	25—30 cm. A	30—35 cm. B	35—40 cm. C	40 cm. and over D	Mean	S. E.
Mean of 4 plots . . .	9·78	9·36	8·48	8·43	9·01	0·083
Per cent of mean . . .	108·5	103·9	94·0	93·5	100·00	±0·921

z significant ($P<0·01$)
C. D. (5 per cent) = 0·287 or 3·187 per cent

A B C D

TABLE VI

Taungdeikpan—final stem numbers

Height of seedlings	25—35 cm. A	35—45 cm. B	45—55 cm. C	55 cm. and over D	Mean	S. E.
Mean of 4 plots . . .	10·72	9·55	9·03	8·66	9·49	0·308
Per cent of mean . . .	112·9	100·6	95·2	91·3	100·00	±3·247

z significant ($P<0·05$)
C. D. (5 per cent) = 1·067 or 11·236 per cent
A B C D

TABLE VII

Mean numbers of stems formed at different ages by seedlings of different heights ; varieties—Taungdeikpan and Ngasein, 1933

Height class	A		B		C		D	
Days from transplanting	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan	Ngasein	Taungdeikpan
0 . . .	1·00	1·00	1·00	1·10	1·00	1·14	1·08	1·43
11 . . .	1·03	1·08	1·02	1·19	1·03	1·28	1·09	1·41
25 . . .	1·55	2·50	1·80	2·60	1·88	3·69	2·25	3·25
39 . . .	4·24	6·71	4·99	6·80	4·95	7·68	5·88	7·38
53 . . .	9·15	12·32	10·08	11·59	9·32	11·45	10·18	11·39
67 . . .	11·60	14·39	12·30	12·75	11·13	11·83	11·83	11·47
81 . . .	14·03	15·47	13·91	12·86	12·29	11·53	12·14	11·09
95 . . .	12·83	12·69	12·05	11·03	11·05	10·16	10·76	9·61
109 . . .	9·78	10·72	9·37	9·55	8·48	9·03	8·42	8·66
Per cent deaths .	30·3	30·7	32·6	25·7	31·0	23·7	30·6	24·5

(Height classes as in Tables V and VI)

Fig. 5 shows the interpolated dates of formation of tillers T_1-T_8 for each class of seedling in both

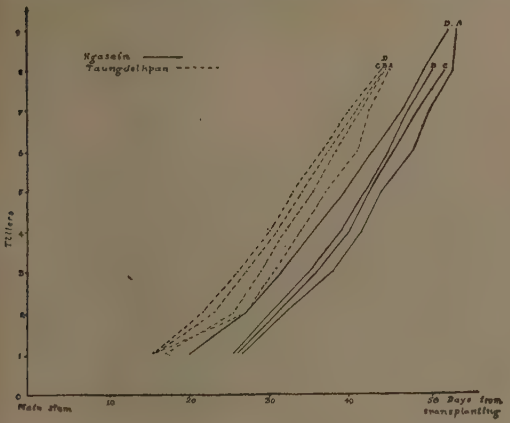

FIG. 5. Interpolated dates of formation of tillers 1-8 for four seedling sizes of Ngasein and Taundeikpan. (Not carried beyond T8 because deaths supervene at about that time)

varieties. The earlier tillering of Taungdeikpan is clearly brought out. In this variety the C class seedlings tillered first, being followed by D, B and A in that order. In Ngasein the tallest seedlings (D) tillered first followed by C, B and A in that order, so that in this case the taller the seedlings the earlier did it form tillers although it did not form so many.

HEIGHT OF SEEDLING AND YIELD

The close connection between the yield and number of tillers matured leads to a corresponding influence of seedling size on yield of grain. The figures in Table VIII for yields of grain from 50 random plants from each plot in the preceding experiment show the influence of seedling height on yield.

These results are in agreement with the effect of seedling height on final tiller number, and show that small to medium size seedlings tiller more and yield better than tall ones. Birkinshaw [1940] states that the greatly increased growth in nurseries following manuring does not lead to increased yields in the field. The results here reported would seem to indicate that any advantage from the manuring of nurseries must come not from the greater size of the seedlings but from the earlier attainment of a size suitable for earlier transplanting, so leading through earlier commencement of tillering to enhanced yields.

TABLE VIII

Grain yields from seedlings of differenct heights ; Ngasein and Taungdeikpan, 1933

Seedling height class		A	B	C	D	Mean	S. E.	C. D. (5 per cent)
Ngasein	Mean of 4 plots	22·97	23·48	19·97	20·11	21·63	0·70	2·43
	Per cent .	106·2	108·5	92·3	93·0	100·0	3·24	11·23
Taungdeik-pan	Mean of 4 plots	29·37	25·85	25·14	23·52	25·97	1·13	3·89
	Per cent . .	113·1	99·5	96·8	90·6	100·0	4·33	14·98

For values of A—D see Tables V and VI

Ngasein = B A D C

Taungdeikpan = A B C D

EARLY TILLERING

Since there is a high correlation between the order of a tiller and its liability to death (Tables II and III) the earlier a tiller is formed the better chance it has of surviving to contribute towards the yield. The linear regression coefficients of the number of stems formed by 2 September 1932 on final number matured are given below :

	b	
Ngakyi	3·61	$P<0{\cdot}01$
Ngasein	3·15	
Taungdeikpan	2·88	
Paungmalaung	4·04	

These figures are derived from plots planted with seedlings of mixed size. In 1933 using plots planted with seedlings of uniform height the same relationship holds good for each size of seedling, giving the following linear regression coefficients :

		b
Taungdeikpan	A	$1\cdot02\pm0\cdot09$
	B	$0\cdot73\pm0\cdot04$
	C	$0\cdot61\pm0\cdot07$
	D	$0\cdot58\pm0\cdot04$
Ngasein	A	$1\cdot13\pm0\cdot09$
	B	$0\cdot78\pm0\cdot11$
	C	$0\cdot86\pm0\cdot36$
	D	$0\cdot69\pm0\cdot02$

(A—D as in Tables V and VI)

These coefficients are all much smaller than those for the 1932 crop and the Ngasein C class is not significant. For the rest the importance of early transplanting and a quick recovery from the damage of that operation is clear. Fig. 6 is for the Taungdeikpan A class seedlings. The others are similar and are not given here.

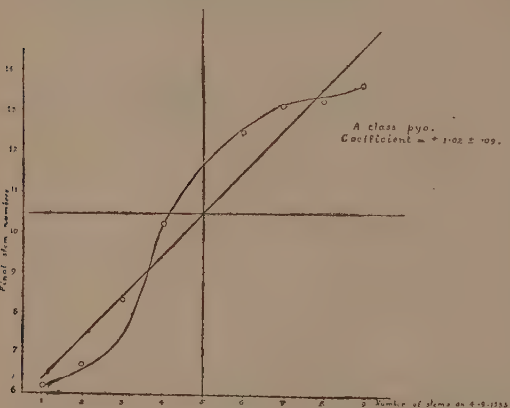

FIG. 6. Regression of early stem number on final stem number for Taungdeikpan in 1933

ORDER OF TILLERING AND WEIGHT OF PANICLE

Engledow and Wadham [1924] noted the tendency for weight of grains, straw and rachis to decrease in later-formed barley tillers. Our data for 1932 show a negative correlation between the number of stems per plant and the mean panicle weight.

	r	
Ngakyi	—0·384	$P<10^{-8}$
Ngasein	—0·425	„ 10^{-5}
Taungdeikpan	—0·304	$P<10$

(Paungmalaung is omitted because of sparrow damage)

Although the correlations are highly significant the fact that the relationship is not linear has resulted in comparatively low figures for r, the polynomial curve being sigmoid.

Since the panicle weight is largely made up by the weight of grains it follows that the relationship between the order of tillering and the number of filled grains per panicle will represent the effect of the order of the tiller on its contribution towards the final yield (Table IX).

These figures show that the later a tiller is formed the fewer good grains it matures, an additional reason for promoting early tillering as much as possible.

From the regression coefficients it appears that for Taungdeikpan a delay of one week in tiller formation may reduce the number of grains matured by 11 to 13 and for Ngasein from 3·7 to 9·7. In both varieties the crowding effect at the closer spacing is very evident.

In 1935 these experiments were repeated with the addition of group planting (*htonsan*). The correlations between order of tillering expressed as the number of days from sowing to date of recording the tiller and the mean panicle weight were very high.

	Htonsan	1 ft. × 1 ft.	2 ft. × 2 ft.
Taungdeikpan	—0·96	—0·91	—0·98
Ngasein	—0·96	—0·98	—0·99

TABLE IX

Correlation and regression coefficients between order of tillering and mean number of good grains per panicle 1933 and 1934

Plant spacing	Taungdeikpan				Ngassein			
	Correlation coefficient r		Regression coefficient b		Correlation coefficient r		Regression coefficient b	
	1933	1934	1933	1934	1933	1934	1933	1934
1 ft. × 1 ft.	—·93 $P<$ ·01	—·89 $P<$ ·01	—13·89±1·73	—12·48±3·02	—·79 $P<$ ·01	—·98 $P<$ ·01	—9·73±2·66	—8·41±·73
2 ft. × 2 ft.	—·91 $P<$ ·01	—·98 $P<$ ·01	—11·22±1·25	—13·62±0·88	—·88 $P<$ ·01	—·99 $P<$ ·01	—3·80±0·60	—6·75±·31

Whether the relationship is expressed as between order of tillering and panicle weight, as above, or order of tillering and grain weight is immaterial, since in both cases the correlations are high. The regression coefficients corresponding to these data vary little and average for the six sets 0·035, that is to say a delay of one day in tiller formation will entail a loss in panicle weight of 0·035 gm. on average.

Not only does delay in tiller formation result in a drop in mean panicle weight and mean weight of grain per panicle but it also leads to a reduction in individual grain size at close spacings. In Table X the mean weights of grains from early and late tillers are given.

TABLE X

Comparison of grain weights (gm.) from early and late tillers

	Mean wt. Early tillers	Mean wt. Late tillers	S. E. difference	Significance
Taungdeikpan—				
1 ft. × 1 ft.	·0184	·0172	±·00048	S
2 ft. × 2 ft.	·0178	·0176	±·00020	NS
Ngasein—				
1 ft. × 1 ft.	·0262	·0246	±·00038	S
2 ft. × 2 ft.	·0263	·0258	±·00026	NS

At the closer spacing the weight of the grains on early tillers is significantly greater but in the case of the wider-spaced plants the difference is too small to be relied on. Where space is limited it may be concluded that heavier grain is borne on the earlier tillers, which at the same time bear more grains. The major contribution towards the yield therefore comes from the earlier tillers because these have a greater survival value and bear heavier panicles with larger grains. In Table XI the percentage of the total grain yield contributed by the tillers recorded at weekly intervals are shown and the general decline in the fruitfulness of the later-formed tillers is clear. (It is not possible with paddy to record each tiller in order of formation, as has been done for wheat, because often two or more tillers are formed at nearly the same time).

Besides the declining importance of later tillers the effect of crowding is to concentrate a greater proportion of the yield in the main stems and early tillers. Whereas only 10-13 per cent of the yield is contributed by the main stems at 2 ft. × 2 ft. spacing, over 20 per cent is accounted for at the *htonsan* spacing. This *htonsan* method of planting, however, comprises four to seven plants in a group, that is to say four to seven main stems, but even so the increasing contribution by main stems or early tillers with closer spacing is clear. It is therefore to be expected that anything which will promote early commencement of tillering after transplanting is likely to promote yield. This may be effected by such methods as early transplanting (which requires nursery operations to provide good seedlings at an early date), application of quick-acting fertilizers which will promote a quick onset of tillering and a planting distance which will not cause overcrowding at an early stage.

TABLE XI

Order of tillering and percentage yield (in weight) of grains

(Mean of 12 plants)

(Sown on 16-6-34. Transplanted on 27-7-34)

Recording dates	Ngasein		Taungdeikpan		
	Htonsan	2 ft. × 2 ft.	*Htonsan*	1 ft. × 1 ft.	2 ft. × 2 ft.
Main stems	21·9	10·4	20·0	14·6	12·8
13-8-34	19·5	11·8	19·2	13·8	14·0
20-8-34	17·3	11·4	19·7	14·0	13·0
27-8-34	15·5	11·1	14·6	10·8	10·6
3-9-34	15·4	10·2	9·9	9·8	10·3
10-9-34	10·4	9·5	10·1	8·7	9·5
17-9-34	..	8·9	6·5	8·2	9·1
24-9-34	..	8·1	..	9·7	8·1
1-10-34	..	7·2	..	7·5	7·0
8-10-34	..	6·0	..	..	5·6
15-10-34	..	5·4	..	..	..

(Ngasein 1 ft. × 1 ft. omitted owing to an error in the records which are now not available)

In Table XII the regressions are calculated to show the delay in flowering for each week's delay in tiller formation. The figures show that in round numbers a delay of one week in tiller formation at 1 ft. × 1 ft. spacing entails a delay of 0·55 day in flowering while at 2 ft. × 2 ft. spacing this delay increases to about 0·74 day. Since as long as 11 weeks may intervene between the dates of formation of the first and last tillers, the flowering would, on these results, spread over about eight days. The flowering does, in fact, extend over about nine or ten days. The greater delay in flowering of late tillers at the wider spacing is due, in part at least, to the longer period over which tillers capable of flowering continue to be produced, and in part to the crowding effect at the closer spacing which always induces earlier flowering.

Order of tillering and flowering date

TABLE XII

Correlations and regressions between date of formation and date of flowering of tillers

—		1933		1934	
		r Correlation coefficient	*b* Regression coefficient	*r* Correlation coefficient	*b* Regression coefficient
Taungdeikpan	1 ft. × 1 ft. . . .	+·60±·067	+·56±·062	+·42±·068	+·69±·113
,,	2 ft. × 2 ft. . . .	+·56±·045	+·81±·064	+·47±·044	+·84±·077
Ngasein	1 ft. × 1 ft. . . .	+·57±·074	+·57±·073	+·27±·083	+·42±·128
,,	2 ft. × 2 ft. . . .	+·65±·043	+·85±·057	+·44±·048	+·47±·052

Summary

Tillering begins about a fortnight after transplanting and the rate quickly reaches a maximum, after which a steady decline sets in until by the beginning of November only a small number of tillers are produced.

Tiller deaths commence about the beginning of October at close spacing, somewhat later at wider spacing, and the death rate tends to increase as the season advances. The tillering shows modes which closely correspond in the different varieties and at different spacings indicating some common influencing factor. The rainfall in 10-day totals exhibits similar modes but preceding the tillering modes by about 15 days. It is suggested that the two phenomena are interconnected.

The liability of tillers to premature death is shown to increase as the recording date advances until at close spacing the late-formed tillers have no chance of surviving. At the 2 ft. × 2 ft. spacing all tillers have some chance of reaching maturity. There does not appear to be any critical period of tillering such as the Cambridge workers found for wheat and barley. The liability to premature death is not confined to the late-formed tillers only, but death may occur to the main stem itself or any other stems. With group planting as many as 20 per cent of the main stems may die prematurely.

It is not necessarily the tallest seedlings which tiller and yield best. It was found that in general the shortest seedlings gave the largest number of surviving tillers at harvest, and because of the close relationship between tillering and yield, these gave the greatest final yield. The tallest seedlings formed tillers most rapidly in the early stages but did not mature as many as the shorter ones.

The earlier a tiller is formed the better its chance of surviving to contribute to the yield. Early transplanting may therefore be expected to enhance yield and manuring of nurseries to bring seedlings to a transplantable size at an early date will be beneficial.

The later a surviving tiller is formed the smaller is the share of the total yield contributed by it, because the panicle weight, the number of filled grains and the mean grain weight progressively decline as the tillering date advances. Crowding tends to concentrate a larger portion of the total yield in the main stems and early tillers.

The correlation between date of formation of a tiller and the date of its flowering is definite, a delay of one week in tillering postponing flowering on average about half to three-quarters of a day.

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APPENDIX

Tables of summed stem numbers for 12 plants selected at random, 1933

TABLE I

Record of tillers (including main stems) 1933

Theikpan Taungdeikpan 1 ft. × 1 ft. spacing. Transplanted on 3-8-1933

	15th Aug. 1	22nd Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	10th Nov. 15	14th Nov. 16
Total tillers formed	*	35	*	34	17	*	29	24	*	21	14	6	3	1	1	1
Progressive total	*	35	*	69	86	*	115	139	*	160	174	180	183	184	185	186
Deaths	*	...	*	...	...	*	...	...	*	1	2	7	3	2	8	3
Number survived	*	35	*	69	86	*	115	139	*	159	171	170	170	169	162	160

* Counts not taken

TABLE II

Record of tillers (with main stems) 1933

Ngasein C401 2 ft. × 2 ft. spacing. Transplanted on 28-7-1933

	15th Aug. 1	21st Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	14th Nov. 15	20th Nov. 16	24th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	35	*	35	50	45	23	46	58	27	23	39	15	8	4	24	4	2	4	1
Progressive total	35	*	70	120	165	188	234	292	319	342	381	396	404	408	432	436	438	442	443
Deaths	...	...	...	...	...	...	...	...	...	5	9	16	29	22	13	14	1	1	5
Number survived	35	*	70	120	165	188	234	292	319	337	367	366	345	327	338	328	329	332	328

* Counts not taken

TABLE III

Record of tillers (with main stems) 1933

Ngasein C401 1 ft. × 1 ft. spacing. Transplanted on 3-8-1933

	15th Aug. 1	21st Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	10th Nov. 15	14th Nov. 16	20th Nov. 17	24th Nov. 18	8th Dec. 19
Total tillers formed	*	29	*	17	21	*	24	15	*	21	31	6	8	1	*	4	2	1	1
Progressive total	*	29	*	46	67	*	91	106	*	127	158	164	172	173	*	177	179	180	181
Deaths	...	...	...	...	...	...	...	...	...	...	1	13	12	6	*	3	1	2	0
Number survived	*	29	*	46	67	*	91	106	*	127	157	150	146	141	*	142	143	142	143

* Counts not taken

TABLE IV

Record of tillers with main stems (Sums of 12 plants) *1933*

Theikpan Taungdeikpan 2ft. × 2ft. spacing. Transplanted on 28-7-1933

	15th Aug. 1	22nd Aug. 2	29th Aug. 3	6th Sept. 4	12th Sept. 5	16th Sept. 6	22nd Sept. 7	26th Sept. 8	30th Sept. 9	5th Oct. 10	13th Oct. 11	19th Oct. 12	26th Oct. 13	2nd Nov. 14	9th Nov. 15	14th Nov. 16	20th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	34	...	29	61	34	14	62	66	48	21	43	17	6	4	0	8	1	0	0
Progressive total	...	...	63	124	158	172	234	300	348	369	412	429	435	439	439	447	448	448	448
Deaths	...	...	...	...	...	...	...	...	...	...	3	5	11	22	17	13	13	5	5
Number survived	34	...	63	124	158	172	234	300	348	369	409	421	416	398	381	376	364	359	354

TABLE V

Ngasein 2 ft. × 2 ft. 1934

Totals of 12 plants

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17	30th Nov. 18	8th Dec. 19
Total tillers formed	12	22	25	55	71	51	74	48	45	44	40	7	...	...	...	...	...	...	...
Progessive total	12	34	59	114	185	236	310	358	403	447	487	494	...	...	...	...	...	...	...
Deaths	...	...	...	...	...	...	2	3	4	4	10	12	38	34	2	14	3	0	1
Number Survived	12	34	59	114	185	236	308	353	394	434	464	459	421	387	385	371	368	368	367

TABLE VI

Ngasein 1 ft. × 1 ft. 1934

Totals of 12 plants

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17	8th Dec. 18
Total tillers formed	12	15	21	44	54	36	26	15	3	3	2	0	1	...	...	...	...	...
Progressive total	12	27	48	92	146	182	208	223	226	229	231	231	232	...	...	...	...	...
Deaths	...	...	...	...	...	...	2	1	26	5	26	1	10	2	3	3	0	1
Number survived	12	27	48	92	146	182	206	220	197	195	171	170	161	159	156	153	153	152

TABLE VII

Ngasein htonsan 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	13th Nov. 15	19th Nov. 16	26th Nov. 17
Total tillers formed	*32	36	42	43	31	11	5	1	0	2	...	...	...	...	...	...	...
Progressive total	32	68	110	153	184	195	200	201	201	203	...	...	...	...	...	...	...
Deaths	...	...	...	...	...	3	5	8	26	3	21	3	7	8	2	2	...
Number survived	32	68	110	153	184	192	192	188	162	161	140	137	130	122	120	118	...

*Mean number of plants per hill = 2·51

TABLE VIII

Taungdeikpan 2 ft. × 2 ft. 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	12th Nov. 15	19th Nov. 16
Total tillers formed	12	28	37	68	73	54	60	89	65	38	3	2	...	...	...	...
Progressive total	12	40	77	145	218	272	332	421	486	524	527	529	...	...	...	...
Deaths	...	...	...	...	...	2	5	1	3	1	14	15	19	23	12	7
Number survived	12	40	77	145	218	270	325	413	475	512	501	488	469	446	414	407

TABLE IX

Taungdeikpan 1 ft. × 1 ft. 1934

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14	12th Nov. 15	19th Nov. 16
Total tillers formed	12	26	26	51	51	33	35	28	2	2	4	...	...	...	...	...
Progressive total	12	38	64	115	166	199	234	262	264	266	270	...	...	...	...	...
Deaths	...	...	...	...	1	0	4	3	17	4	23	4	14	4	4	3
Number survived	12	38	64	115	165	198	229	254	239	237	218	214	200	196	192	189

TABLE X

Taungdeikpan htonsan 1934

Totals of 12 groups

	27th July 1	13th Aug. 2	20th Aug. 3	27th Aug. 4	3rd Sept. 5	10th Sept. 6	17th Sept. 7	24th Sept. 8	1st Oct. 9	8th Oct. 10	15th Oct. 11	22nd Oct. 12	30th Oct. 13	5th Nov. 14
Total tillers formed	*25	48	32	26	12	9	4	5	0	1	...	...	...	...
Progressive total	25	73	105	131	143	152	156	161	161	162	...	...	...	...
Deaths	...	...	...	1	5	3	8	12	8	2	8	2	4	4
Number survived	25	73	105	130	137	143	139	132	124	123	115	113	109	105

* Mean number of plants per hill = 2·09

A STUDY OF THE CHANGES IN THE QUALITY OF PUNJAB-AMERICAN 289F/43 COTTON WITH VARIATIONS IN THE DATES OF SOWING AND WITH PROGRESSIVE PICKINGS*

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(Received for publication on 18 May 1942)

The date of sowing has a very important bearing on the development and yield of the cotton plant and literature abounds in instances where a change in the normal dates of sowing has been instrumental in increasing the yield or protecting the crop from the attack of insect pests and diseases.

In the early days of the introduction of American cotton in the Punjab the best time of sowing was considered to be from the end of March to the end of April. As time went on and more critical experiments were performed, a tendency for shifting the dates of sowing became evident. The periodic partial failures of American cotton accentuated this tendency towards later sowing as it was observed that late-sown cotton suffered less from *tirak* (bad opening of bolls) than the early-sown crop [Anonymous, 1937]. The Department of Agriculture, Punjab, now recommends 15 May to 15 June as the optimum period for sowing cotton in a major portion of the Canal Colonies and from the end of May to the end of June in the south-western districts of the province. The zemindars of these tracts have not been slow in acting on this recommendation and had, in fact, come to the same conclusion almost simultaneously with the Departmental workers in the early thirties. It has also been established that American cotton sown before the optimum period suffers more from *tirak*. In order, however, to get a quantitative idea of the effect of either early, normal or late sowing and the time of picking of the crop on fibre-properties properly laid out experiments have been carried out and the present paper deals with the data obtained from these experiments.

Previous literature

It is not proposed to review the previous literature on the field behaviour of the crop sown at different times. References on the effect of date of sowing on fibre-properties are unfortunately lacking except that of a former worker in the Cotton Research Laboratory, Lyallpur [Sen, 1934, 1], who did not find any change in the length and fineness of the fibre of Punjab-American 4F and 289F/43 when sown on 15 April, 5 May, 20 May and 3 June. The study on P.-A. 289F/43 has now been pursued further by including a larger variation in the dates of sowing combined with progressive pickings and by determining a larger number of fibre characters.

Material and method

P.-A. 289F/43 was sown in 1937 in randomized blocks using five dates of sowing and seven replications. The dates of sowing were: 15 April, 5 May, 20 May, 4 June and 1 July. The following procedure was adopted for collecting the samples:

Four normal plants were selected at random from each bed in the beginning of the picking season. All the well-opened bolls on these four plants were picked every week in separate bags. Pickings were made on the same day of the week in all the beds throughout the season. Pickings commenced on 27 September 1937 in the case of the first, second, third and the fourth sowing dates and 1 November 1937 in the case of the fifth sowing date and continued at weekly intervals up to 10 January 1938 in all cases.

The *kapas* picked from all the beds under the same sowing date was mixed for each picking and ginned. This procedure reduced the number of samples to within a workable limit. At the time of fibre tests, the samples of the first picking (27 September 1937) from the first, second, third and the fourth sowing dates were not tested for fibre characters as there was an uncertainty in the period during which the bolls picked on this date had opened; the samples from the last picking (10 January 1938) of all sowings were also not tested as the quantity of lint available in this case was very small. The remaining 66 samples, representing 14 pickings each of the first four sowing dates and 10 pickings of the fifth sowing, were available for testing.

Slivers were prepared by the usual sampling methods, drafted, cleaned and redrafted with the Balls sorter draw-box and were used for the determination of the following fibre characters:

(1) Balls sorter mean length
(2) Balls sorter modal length
(3) Balls sorter fibre-length irregularity (per cent)
(4) Mean fibre-weight per unit length
(5) Percentage of mature fibres and
(6) Highest standard warp counts.

*Read at the Indian Science Congress, Baroda, January 1942

TABLE I

Picking date	Sowing date					Sowing date					Sowing date				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
	(15.4.37)	(5.5.37)	(20.5.37)	(4.6.37)	(1.7.37)	(15.4.37)	(5.5.37)	(20.5.37)	(4.6.37)	(1.7.37)	(15.4.37)	(5.5.37)	(20.5.37)	(4.6.37)	(1.7.37)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	(*a*) Balls sorter mean length (cm.)					(*b*) Balls sorter modal length (cm.)					(*c*) Fibre length irregularity (per cent)				
4.10.37	2·15	2·24	2·32	2·26	..	2·39	2·56	2·63	2·55	..	25·6	25·3	23·0	25·2	..
11.10.37	2·14	2·35	2·35	2·39	..	2·36	2·65	2·65	2·68	..	22·3	24·3	23·6	24·0	..
18.10.37	2·08	2·32	2·18	2·19	..	2·20	2·60	2·42	2·37	..	25·2	25·4	26·4	23·3	..
25.10.37	2·11	2·29	2·13	2·30	..	2·15	2·52	2·29	2·61	..	21·7	25·0	23·0	27·6	..
1.11.37	2·11	2·29	2·24	2·37	2·16	2·13	2·56	2·46	2·63	2·31	21·8	25·6	24·3	24·8	23·8
8.11.37	2·06	2·25	2·21	2·26	2·20	2·07	2·49	2·37	2·55	2·33	20·4	26·4	24·1	27·7	23·3
15.11.37	2·11	2·35	2·28	2·28	2·20	2·20	2·59	2·58	2·50	2·41	21·8	23·2	24·3	24·7	25·6
22.11.37	2·00	2·18	2·22	2·35	2·30	2·05	2·40	2·42	2·56	2·55	22·4	26·0	21·8	24·2	26·6
29.11.37	2·02	2·26	2·22	2·28	2·34	2·05	2·51	2·42	2·61	2·60	20·6	25·4	24·5	27·9	25·2
6.12.37	1·92	2·20	2·31	2·31	2·26	2·00	2·40	2·60	2·60	2·44	22·5	24·8	23·8	23·7	24·1
13.12.37	2·22	2·24	2·20	2·24	2·30	2·42	2·45	2·40	2·44	2·56	24·8	23·6	23·4	23·2	26·1
20.12.37	1·92	2·04	2·12	2·09	2·14	1·95	2·16	2·26	2·14	2·25	22·9	24·8	22·6	22·7	22·0
27.12.37	1·83	2·01	1·96	2·14	1·98	1·76	2·06	1·98	2·26	2·05	17·1	20·7	21·0	19·4	23·7
3.1.38	1·79	2·03	2·06	2·10	1·84	1·83	2·04	2·13	2·21	1·83	21·6	20·8	23·6	22·5	21·7
	(*d*) Mean fibre weight per unit length (10—6 gm./cm.)					(*e*) Percentage of mature fibres					(*f*) Highest standard warp counts (calculated)				
4.10.37	0·96	1·16	1·16	1·23	..	23	20	24	27	..	38·7	39·0	41·4	39·1	..
11.10.37	1·25	1·30	1·33	1·37	..	27	31	31	26	..	35·2	41·0	40·8	40·8	..
18.10.37	1·15	1·25	1·18	1·05	..	20	34	26	15	..	33·5	40·7	36·4	38·4	..
25.10.37	0·96	1·26	1·23	1·30	..	25	32	36	40	..	37·7	40·1	35·7	40·2	..
1.11.37	0·92	1·21	1·24	1·22	1·26	26	34	41	34	36	38·2	41·0	39·0	42·9	36·6
8.11.37	1·00	1·33	1·26	1·33	1·22	25	47	34	35	30	35·6	39·0	37·6	38·0	37·1
15.11.37	1·12	1·36	1·41	1·45	1·34	19	43	45	34	34	34·3	41·0	38·8	37·0	36·5
22.11.37	0·94	1·26	1·42	1·31	1·24	16	38	46	38	30	33·7	36·8	36·8	41·1	40·3
29.11.37	1·06	1·33	1·27	1·36	1·35	12	35	42	43	32	31·9	37·9	38·5	39·1	40·2
6.12.37	0·91	1·19	1·41	1·35	1·18	9	35	49	37	27	30·7	38·3	39·6	39·5	39·9
13.12.37	1·27	1·17	1·33	1·29	1·20	27	41	41	41	25	36·7	40·4	37·3	38·7	39·9
20.12.37	0·98	1·16	1·21	1·32	1·20	13	26	31	38	14	30·9	33·4	35·2	33·3	34·3
27.12.37	0·84	1·14	1·20	1·21	1·00	3	18	14	23	9	27·9	32·6	28·8	35·2	31·0
3.1.38	0·98	1·01	1·10	1·10	0·74	7	13	20	16	1	25·7	33·3	34·6	35·1	29·4

The methods followed in the determination of the first four characters were the same as described by Ahmad [1933] and in the determination of the percentage of mature fibres, the method of Gulati and Ahmad [1935] was adopted using their new device for mounting fibres [Ahmad and Gulati, 1936]. The above five fibre characters were converted into a quantity 'highest standard warp counts' (H. S. W. C.) according to an equation given recently by Ahmad [1941]. The calculated H. S.W.C. served to express the results of fibre-tests as a single quantity suited to quantitative analysis. The data obtained for the five fibre characters as well as the H. S. W. C. calculated therefrom are presented in Table I.

Analysis of results

(*a*) The values of fibre characters of samples from the fifth sowing date are not included in the analysis given below mainly because the first picking from this sowing date was available only on 1 November 1937 and not on 27 September 1937 as in the case of the other four sowing dates.

There were 14 pickings in each of the first four sowing dates and analysis of variance could be applied to the six sets of 56 observations each of the six fibre characters taking one set after another. The values of mean squares and their significance obtained from this analysis are set out in Table II. It will be seen from Table II that the variances due to sowing dates were highly significant in respect of all fibre characters, excepting the fibre-length irregularity in which case also the significance was nearly at 2 per cent level, showing in general a real variation in all the fibre characters studied with a variation in sowing date.

From the table of mean values (Table III) it is apparent that the fibre characters of samples from the first sowing date were all significantly lower than those of samples from the other three sowing dates, which did not vary significantly among themselves.

TABLE II

Values of mean square

Source of variation	D. F.	Mean fibre-length	Modal length	Fibre-length irregularity	Mean fibre-weight per unit length	Percentage of mature fibres	Highest standard warp counts (calculated)
Sowing dates .	3	0·1350827**	0·3834684**	14·71494*	0·1964066**	775·0714**	69·4369**
Residual .	52	0·0123435	0·0360345	3·68454	0·0117257	87·9368	10·2024

*Significant at 5 per cent level
**Significant at 1 per cent level

TABLE III

Mean values of fibre characters of the I, II, III and IV sowing dates

Fibre character	Sowing date I (15-4-37)	II (5-5-37)	III (20-5-37)	IV (4-6-37)	Critical difference between two means
1. Mean fibre-length (cm.)	2·033	2·218	2·200	2·254	±0·0891
2. Modal length (cm.)	2·111	2·428	2·401	2·479	±0·1522
3. Fibre-length irregularity (per cent) . .	22·19	24·38	23·53	24·35	±1·539
4. Mean fibre-weight per unit length (10^{-6} gm/cm.)	1·024	1·224	1·268	1·278	±0·0868
5. Percentage of mature fibres . . .	18·00	31·93	34·29	31·93	±7·519
6. Highest standard warp counts (calculated)	33·62	38·18	37·18	38·46	±2·5607

The conclusion drawn from the above analysis was that the first sowing date, as early as about the third week of April, was not desirable from considerations of lint quality. The second sowing date had not, in this year, produced lint of a quality any different from that of the third and the fourth sowing dates, which, *inter se*, did not show any significant difference in the quality of lint.

(*b*) As the first picking in the fifth sowing date was available only on 1 November 1937, the fibre characters of pickings from this sowing could not be included in the above analysis of variance for the study of variation in lint quality with changes in sowing dates. The following method was, therefore, adopted to compare the lint quality of pickings from the fifth sowing with that of pickings from the other sowings. No rigorous

validity is claimed for the method which was used only in the absence of a better one.

The average in each picking of values of fibre characters of samples from the second, third and the fourth sowing dates, in all pickings made on and after 1 November, was compared with the fibre characters of the corresponding pickings from the fifth sowing date by the method quoted by Tippett [1937]. The working is given in detail in Table IV for mean fibre-length only for purposes of illustration and the compiled mean values of fibre characters and the significances of the differences between them are brought out in Table V.

TABLE IV

Date of picking	Mean fibre-length (cm.) Average value for the II, III and the IV sowing dates	Value for the V sowing date	Difference d	Sums of squares of d measured as deviations from $\bar{d}=0\cdot0934$
1-11-37	2·30	2·16	0·14	$t = \dfrac{\bar{d}}{\frac{S}{\sqrt{N}}}$
8-11-37	2·24	2·20	0·04	
15-11-37	2·30	2·20	0·10	$= \dfrac{\frac{0\cdot30}{10}}{\sqrt{\frac{0\cdot0934}{9}} \times \frac{1}{\sqrt{10}}}$
22-11-37	2·25	2·30	−0·05	
29-11-37	2·25	2·34	−0·09	
6-12-37	2·27	2·26	0·01	
13-12-37	2·23	2·30	−0·07	
20-12-37	2·08	2·14	−0·06	
27-12-37	2·04	1·98	0·06	$=0\cdot9312$ and $n=9$
3-1-38	2·06	1·84	0·22	The above t is non-significant
Sums	22·02	21·72	0·30	

TABLE V

Fibre character	Mean value: Of averages for the II, III and IV sowing dates	For the V sowing date	Difference (col. 2-col. 3).	D. F.	
1	2	3	4	5	6
1. Mean fibre-length (cm.)	2·202	2·172	0·03	9	0·9312
2. Modal length (cm.)	2·393	2·333	0·06	9	1·2696
3. Fibre-length irregularity (per cent)	23·86	24·21	—0·35	9	0·5400
4. Mean fibre-weight per unit length 10^{-6} gm./cm.)	1·265	1·173	0·092	9	2·7020*
5. Percentage of mature fibres	34·4	23·8	10·6	9	6·4596**
6. Highest standard warp counts (calculated)	37·33	36·52	0·81	9	1·037

*Significant at 5 per cent level
**Significant at 1 per cent level

It was found that, while the differences in mean fibre-length, modal length and fibre-length irregularity were all non-significant, the difference in mean fibre-weight per unit length was significant and that in the percentage of mature fibres highly so. The difference in the calculated H. S. W. C., however, was not significant. This might be due to the following reasons. The total correlation coefficient [Ahmad, 1941] between H. S. W. C. and mean fibre-length is as high as $=+0\cdot878$ when compared with that between H. S. W. C. and mean fibre-weight per unit length, viz. $r= -0\cdot812$ and that between H. S. W. C. and percentage of mature fibres, viz. $r=-0\cdot319$. Hence the non-significant difference in the mean fibre-length probably masked the effect of the significant differences in mean fibre-weight per unit length and percentage of mature fibres.

From a study of differences in fibre characters from picking to picking, expressed as the excess of the average of the second, third and the fourth sowing dates over the fifth sowing date, it was

found that the mean fibre-weight per unit length and the percentage of mature fibres in pickings from the fifth sowing date were uniformly lower than those in pickings from the second, third and the fourth sowing dates in each picking individually, excepting the mean fibre-weight per unit length of pickings from 1 and 29 November. The mean fibre-length and characters derived therefrom as well as the calculated H. S. W. C. were not so consistently different. This showed that the significantly lower mean fibre-weight and percentage of mature fibres in pickings from the fifth sowing date were not only an aggregate effect but true in each individual picking.

These results indicated that the quality of lint in pickings from the fifth sowing date was, on the aggregate, similar to that of lint in corresponding pickings from the second, third and the fourth sowing dates mainly because of the non-significant difference in mean fibre-length, which rendered the difference in calculated H. S. W. C. also non-significant by masking the effect of the significant differences in mean fibre-weight per unit length and percentage of mature fibres. But the lower percentages of mature fibres in pickings from the fifth sowing date would certainly detract from the quality of the yarn spun from these pickings by introducing such factors as neppiness which are known to be caused, *inter alia*, by immature fibres.

Variations in lint with progressive pickings

The values of fibre characters of pickings from the first sowing date were omitted from further considerations due to their low lint quality and analysis of variance was again applied to values of fibre characters of pickings from the second, third and the fourth sowing dates only. The total sum of squares in this analysis was traced to three sources of variation, viz.

(1) variations due to sowing dates,
(2) variations due to pickings, and
(3) residual variations.

The mean square due to sowing dates (Table VI) was non-significant with respect to all fibre characters, excepting that due to mean fibre-length which was just significant at 5 per cent level. This result further confirmed that obtained previously (Table III) that, between themselves, the second, third and the fourth sowing dates did not differ significantly in the quality of lint. This observation was brought out clearly when, as in Table VII of mean values, the critical difference between two values was calculated using the mean square due to residual in this analysis.

Table VI

Values of mean square

Source of variation	D. F.	Mean fibre-length	Modal length	Fibre-length irregularity	Mean fibre-weight per unit length	Percentage of mature fibres	Highest standard warp counts (calculated)
Sowing dates	2	0·010716*	0·022306	3·25575	0·01168215	25·93575	6·32475
Pickings	13	0·027493**	0·089670**	6·54011**	0·0232434**	229·52857**	20·19531**
Residual	26	0·002945	0·007903	1·76533	0·0035475	28·57033	2·84040

* Significant at 5 per cent level
**Significant at 1 per cent level

Table VII

Mean values of fibre characters in the second, third and the fourth sowing dates

Sowing date 1	Mean length (cm.) 2	Modal length (cm.) 3	Fibre-length irregularity (per cent) 4	Mean fibre-weight per unit length (10^{-6} gm./cm.) 5	Percentage of mature fibres 6	Highest standard warp counts (calculated) 7
II (5-5-37)	2·22	2·43	24·3	1·224	31·9	38·18
III (20-5-37)	2·20	2·40	23·5	1·268	34·3	37·18
IV (4-6-37)	2·25	2·48	24·3	1·278	31·9	38·46
Critical difference	±0·0435	±0·0713	±1·065	±0·0478	±4·3	±1·35

The above conclusion that the samples from the second, third and the fourth sowing dates did not show any significant difference among themselves justified the procedure adopted below in considering the variations in fibre characters from picking to picking. The average in each picking of the three values of each fibre character of samples from the second, third and the fourth sowing dates could be treated as the fibre character of that picking. This procedure would also be in consonance with general agricultural practice in the Canal Colonies where the sowing of cotton is distributed, as already mentioned, over a fairly extended period, from the third week of May to the second week of June, and any study of variations in lint quality with progressive pickings must allow for that practice. This study would therefore be more representative of actual agricultural practice than studies of a similar nature which have been previously conducted by Ayyar and Rao [1930], Rao [1933] and Sen [1934, 2] in each of which the sowing was done on a stipulated day and pickings were made at suitable intervals.

The mean square due to pickings (Table VI) was highly significant in the case of all the six fibre characters thus indicating, in aggregate, a real variation in fibre characters due to variation in the time of picking. In Table VIII are given the mean values of the fibre characters for each picking. Considering the length values, it was found that the mean fibre-length remained almost constant, within the limits of variability, in all the pickings from 4 October to 13 December, 1937; thereafter it showed a sudden and significant fall. The modal length and fibre-length irregularity, being characters derived from mean fibre length, showed a similar trend. Much importance is not to be attached, however, to the fall in fibre-length irregularity, which ordinarily would be desirable but, being in this case associated with a fall in the mean fibre-length, did not connote any real improvement in quality. The mean fibre-weight per unit length, after fluctuating a little during the first three pickings, ceased to show any significant difference from picking to picking up to 20 December, after which it fell. The percentage of mature fibres closely followed the variations in the mean fibre-weight per unit length. It must, however, be mentioned that the fall in the mean fibre-weight per unit length, being here associated with a fall in maturity, did not indicate an improvement in lint quality, which it otherwise would, had not maturity also varied. The calculated H. S. W. C. remained constant within the limits of variability in all pickings from 4 October to 13 December, 1937. Thereafter it showed a significant deterioration. On the whole, it could be stated that, while the lint quality did not show any significant difference from picking to picking up to about the middle of December, there was a sudden fall therafter.*

TABLE VIII

Mean values of fibre characters in progressive pickings

Date of picking	Mean length (cm.)	Modal length (cm.)	Fibre-length irregularity (per cent)	Mean fibre weight per unit length (10^{-6} gm./cm.)	Percentage of mature fibres	Highest standard warp counts (calculated)
1	2	3	4	5	6	7
4-10-37	2·27	2·58	24·5	1·18	23·7	39·83
11-10-37	2·36	2·66	24·0	1·33	29·3	40·87
18-10-37	2·23	2·46	25·0	1·16	25·0	38·50
25-10-37	2·24	2·47	25·2	1·26	36·0	38·67
1-11-37	2·30	2·55	24·9	1·22	36·3	40·97
8-11-37	2·24	2·47	26·1	1·31	38·7	38·20
15-11-37	2·30	2·56	24·1	1·41	40·7	38·93
22-11-37	2·25	2·46	24·0	1·33	40·7	38·23
29-11-37	2·25	2·51	25·9	1·32	40·0	38·50
6-12-37	2·27	2·53	24·1	1·32	40·3	39·13
13-12-37	2·23	2·43	23·4	1·26	41·0	38·80
20-12-37	2·08	2·19	23·4	1·23	31·7	33·97
27-12-37	2·04	2·10	20·4	1·18	18·3	32·20
3-1-38	2·06	2·13	22·3	1·07	16·3	34·33
Critical difference	±0·0939	±0·154	±2·301	±0·1032	±9·258	±2·919

*At a conference in December 1940, Mr. V. Venkataraman of the Indian Central Cotton Committee Technological Laboratory, Matunga, Bombay, suggested to one of us that a further application of analysis of variance to the values of fibre-characters of samples from the second, third and the fourth sowing dates in pickings up to 13 December 1937 may bring out any finer variation in lint quality within these pickings. This analysis was carried out and it was found that no finer variations, other than those brought out in the above analysis, were indicated.

The difference in fibre characters of samples picked before and after the middle of December are rendered more marked in Table IX where the average values of these characters are given in columns 2 and 3 respectively. It will be seen that the lint picked before the middle of December

TABLE IX

Fibre character	Average value	
	Up to 15 December 1937	After 15 December 1937
1	2	3
1. Mean fibre-length (cm.)	2·27	2·06
2. Modal length (cm.)	2·52	2·14
3. Fibre-length irregularity (per cent)	24·6	22·0
4. Mean fibre-weight per unit length (10^{-6} gm/cm.)	1·28	1·16
5. Percentage of mature fibres	35·6	21·1
6. Highest standard warp counts (calculated)	39·15	33·5

was, on the average, longer, heavier and maturer than that picked after that date. While the lint obtained from pickings before the middle of December could spin up to 39·0 (calculated) H. S. W. C., that from pickings after that date could spin only up to 33·5 (calculated) H. S. W. C. The quantity of lint yielded after the middle of December being only 5·74 per cent of the total, the advisability of not mixing the yield obtained after this date with that obtained before is too evident to need further emphasis.

The perfectly representative nature of the values of fibre characters of samples used in deriving the above conclusions regarding the variations in lint quality with progressive pickings was demonstrated by the significance of the residual correlation coefficients (r) between the pairs of fibre characters :

(*a*) Mean fibre-length and mean fibre-weight per unit length,

(*b*) Mean fibre-weight per unit length and percentage of mature fibres, and

(*c*) Percentage of mature fibres and mean fibre-length.

TABLE X

Correlation coefficients

Source of variation	D. F.	Correlation coefficients		
		r_{lw}	r_{wm}	r_{ml}
1	2	3	4	5
Sowing dates	2	+0·3606	+0·3426	—0·7526
Pickings	13	+0·7165	+0·8232	+0·5862
Residual	26	+0·0913	+0·6322**	+0·4438*

N.B.—l stands for mean fibre-length ; w stands for mean fibre-weight per unit length ; and, m stands for percentage of mature fibres

*Significant at 5 per cent level

**Significant at 1 per cent level

The values of r are given in columns 3, 4 and 5 of Table X. The modal length and fibre-length irregularity are not included in this analysis as these, being characters derived by calculation from mean fibre-length, would show trends of variation quite similar to that of mean fibre-length. After separating the correlation coefficients due to sowing dates and to pickings, the residual correlation coefficient between the first pair of fibre characters was $r_{lw}=+0\cdot0913$ and that between the second pair $r_{wm}=+0\cdot6322$, and that between the last pair $r_{ml}=+0\cdot4438$. For 25 degrees of freedom the first correlation coefficient was non-significant, the second was significant at 1 per cent level and the last significant at 5 per cent level. This result is in conformity with that obtained by Koshal, Gulati and Ahmad [1940] from quite different considerations altogether.

SUMMARY

In a major portion of the Canal Colonies in the Punjab, the general agricultural practice of sowing cotton extends over a period of about a month from 15 May to 15 June. To study the effect of date of sowing on the quality of lint of P.-A. 289F/43, sowings were carried out in 1937 in randomized blocks with seven replications The dates of sowing were :

I. 15 April
II. 5 May
III. 20 May
IV. 4 June and
V. 1 July.

The third and the fourth sowings were within the range of general agricultural practice, the second was slightly earlier, the first too early and the fifth too late. The lint produced in each of the sowings was tested for the six fibre characters.

(*a*) Mean fibre-length,
(*b*) Modal length,
(*c*) Fibre-length irregularity (per cent),
(*d*) Mean fibre-weight per unit length,
(*e*) Percentage of mature fibrers, and
(*f*) Highest standard warp counts (calculated).

The third and the fourth sowings yielded lint of the same quality. The second sowing, somewhat earlier than in normal agricultural practice, had, in this year, produced lint of the same quality as in the third and the fourth sowings. The first sowing produced lint definitely inferior in quality to those from the second, third and the fourth sowings. The pickings from the fifth sowing were on the aggregate similar in quality to corresponding pickings from the second, third and the fourth sowings even though the lower percentage of mature fibres in the former would detract from the quality of the yarn spun from them by introducing such undesirable factors as neppiness, which are known to be caused, *inter alia*, by immature fibres.

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EFFECT OF DIFFERENTIAL IRRIGATION ON FIELD BEHAVIOUR AND QUALITY OF PUNJAB-AMERICAN 4F COTTON*

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THE Punjab has perhaps the biggest irrigation system in the world. Of the total cultivated area of about 30 million acres under all kinds of crops, about 50 per cent is irrigated from canals, wells, tanks and other sources of water supply. The canals, however, are the biggest source of irrigation, supplying water to more than 70 per cent of the irrigated area. The area under cotton has averaged about 2·8 million acres during the last five years, and of this about 93 per cent or 2·6 million acres is irrigated. About 65 per cent of the total area under cotton in the Punjab is concentrated in the Canal Colonies which comprise the richest districts in the province. Amongst the Canal Colonies, the Lower Chenab Canal Colony, with its headquarters at Lyallpur, is the oldest and most prosperous.

The authorized discharge of the Lower Chenab Canal is 9,900 cusecs in *rabi* (winter) and 11,000 cusecs in *kharif* (summer). The duty of water is 352 acres of which the permissible cultivation is 264 acres. This means that the canal authorities guarantee irrigation to 75 per cent of the cultivated area. The high level of prices of agricultural produce during the early twenties, coupled with a lack of proper appreciation of the water requirements of the various crops, induced the zemindars to sow areas much in excess of the permissible. The inevitable result was that, on account of a larger area under crops than was justifiable on the basis of water supply, all crops received less water with consequent reduction in yield. The canals are run on a very rigid system and while the canal authorities cannot allow a flow larger than the permissible either in the main or the subsidiary channels, the zemindars, having sown bigger areas, are always attempting to lay the blame of lower yields at the door of the canal authorities. This is especially the case with cotton. Experiments were, therefore, designed to find out the optimum water requirements of the Punjab-American cottons, using 4F as the standard, as this variety is the one which is most extensively cultivated.

PREVIOUS LITERATURE

Watering experiments on cotton have not been done on any extensive scale in India.

Milne [1922, 1924] remarked that the failures of cotton occasionally experienced in the Punjab were manifestation of water stress behaviour in abnormal years of low humidity and high temperatures during flowering and fruiting season. He recommended that American cotton should be given two irrigations in September, two in October and one in November or December. King [1922] carried out experiments on the irrigation requirements of Pima cotton in Arizona. He found that heavier yields were obtained with more frequent irrigation. Shantz and Pemeisal [1927] state that 574 $\pm$ 9 lb. of water were required by the cotton plant to produce one lb. of dry matter. This figure compared very favourably with that of wheat and oats in that locality. Beckett and Dunshee [1932] have reported their results on the water requirements of cotton on sandy loam soil in Southern San Joaquin valley of California. They found that 'When grown with available moisture continuously present throughout the season to 5 ft. depth, a full stand of cotton used on an average of 29·5 acre inches'. McDowell [1937] carried out irrigation experiments on Miller loam soil in Arizona using irrigation rates ranging from 2 to 34 acre inches. He found that the highest average yield of lint per acre resulted from the use of 30 acre inches of water.

Ramanatha Ayyar, Ahmad and Thirumalachari [1940] have reported the results of watering experiments on Cambodia cotton. They found that although highest yield was obtained by applying irrigation every week, but irrigation every three weeks was most profitable. They also found that ridging the soil did not result in any economy of water.

EXPERIMENTAL METHODS AND RESULTS

In ecological relation to the cotton plant, the climate of the Canal Colonies could be described as hot and dry during the period of sowing germination and early growth, i.e. during April,

* Read at the Science Congress, Baroda, January 1942

May and June. The period of active vegetative growth—July and August—coincides with the monsoon season when the climate is hot and moist. During both these periods hot winds are very common and there are usually 10-15 dust storms. The main flowering season (September-October) is mild and dry. The picking season, i.e. November, December and early January is usually dry and cold. There is, however, an expectation of light showers about Christmas time. The first frost usually occurs during the third week of December. There are no frosts after 15 February.

The experiment was designed according to the method of Udney Yule in which all treatments were arranged in a systematic order without randomization and there were 8 to 10 replications each year. The area of individual beds was 1/10 acre and non-experimental strips 9 ft. wide, accommodating three rows of cotton, were provided between the experimental beds to eliminate the effect of lateral seepage. The quantity of water applied to each bed at each irrigation was measured by means of Cipolletti weirs [Wadsworth, 1922].

The systems of irrigation under experiment were as follows :

Type I. Irrigation after every three weeks
Type II. Irrigation after every four weeks
Type III. Irrigation after every five weeks

For the first five years of the experiment, these three types of irrigation were applied to both flat beds and ridged plots according to the Egyptian method of sowing cotton which consisted of making ridges 2½ ft. apart, watering them and then dibbling seeds on ridges keeping 15 in. distance between consecutive holes. The uniformity in wetting of ridged and flat plots in consecutive irrigations was obtained by letting in each time a measured quantity of water by means of Cipolletti weirs.

Type IV. First irrigation was given at an interval of three weeks after sowing and subsequent irrigations after every fortnight.

Type V. (Started in 1930). First irrigation three weeks after sowing and subsequent irrigations as for Type VII.

Type VI. (Started in 1930). Irrigation as for Type VII with two or three late irrigations.

Type VII. Zemindari irrigation. Irrigations were given according to the method followed by cultivators. One cultivator in a nearby village was taken as the standard and irrigations to these beds were given on the dates when this cultivator irrigated his cotton. It may here be mentioned that holdings, in general, are not very large and several farmers are served by one channel. The normal interval between successive turns, to any one cultivator, is 12 or 13 days. There are sometimes canal closures which upset this routine. An average programme of irrigation followed by cultivators is as follows :

The first irrigation is given five to seven weeks after sowing, followed by three irrigations at

TABLE I

Irrigations and rainfall

Year		IF	IR	IIF	IIR	IIIF	IIIR	IV	V	VI	VII	Rainfall	Remarks
1928	N	7	7	5	5	5	5	10			6		The number of irrigations in II & III were equal due to interference by rain
	W	16·39	14·89	12·39	11·55	12·50	11·24	24·54			14·59	11·71	
	T	28·10	26·60	24·10	23·26	24·2	22·95	36·2			26·3		
1929	N	6	6	4	4	3	3	9			5		
	W	17·84	17·78	11·15	12·85	9·38	9·03	22·58			13·97	8·64	
	T	26·5	26·4	19·8	21·49	18·00	17·67	31·2			22·6		
1930	N	7	7	5	5	5	5	9	7	6	5		The number of irrigations in II and III were equal due to interference by rain
	W	16·58	18·81	13·11	14·03	12·43	13·86	21·78	16·33	13·96	11·36	5·43	
	T	22·0	24·2	18·5	19·5	17·9	19·3	27·2	21·8	19·4	16·8		
1931	N	6	6	4	4	3	3	7	4	6	5		
	W	17·95	17·88	11·84	11·76	8·97	9·03	20·84	11·08	17·79	15·15	15·73	
	T	33·7	33·6	27·6	27·5	24·7	24·8	36·6	27·4	33·5	30·9		
1932	N	7	7	5	5	4	4	10	7	8	6		
	W	20·07	19·89	24·29	14·22	12·00	12·06	29·25	20·06	23·11	17·15	6·72	
	T	26·8	26·6	21·0	20·9	18·7	18·8	36·0	26·8	29·8	23·9		
1933	N	6	...	4	...	4	...	9	4	5	3		
	W	18·03	...	11·96	...	11·96	...	26·97	12·13	14·89	8·98	13·05	
	T	31·1	...	25·0	...	25·0	...	40·0	25·2	27·9	22·0		
1934	N	6	...	5	...	4	...	9	7	8	6		
	W	17·99	...	15·03	...	12·09	...	26·92	20·94	23·95	17·83	5·48	
	T	23·5	...	20·5	...	17·6	...	32·4	26·4	29·4	23·3		
1935	N	7	...	5	...	4	...	10	7	8	6		
	W	21·09	...	15·07	...	11·85	...	30·02	21·02	24·00	17·98	3·57	
	T	24·7	...	18·7	...	15·4	...	33·6	24·6	27·6	21·5		

N — Number of irrigations
W — Acre inches of water applied through irrigation
T — Total acres inches of water applied (irrigation + rainfall)
F — Flat
R — Ridged

interval of three weeks. The last two irrigations are given at intervals of two weeks.

It must here be mentioned that wide deviations from the above routine are not possible as each cultivator has to distribute his share of water to all his crops.

The programme of irrigation as detailed above had to be modified during monsoon on account of the rain and suitable adjustments had to be made.

The details of irrigation are given in Table I.

Development records

Counts of flower production and boll maturation were kept in all years.

Flower production. Flower counting was done in all treatments every year. For this purpose six plants were chosen at random from each bed and the flowers produced per plant per day were counted. The number of plants chosen for this purpose in the different types of irrigation varied from 48 to 60 according to the number of repetitions in any one year.

The plants in heavily watered beds had a tendency to produce the first flower somewhat later than the plants receiving comparatively less water. King [1922], however, found that 'the plants frequently watered produced a greater number of flowers during the first 45 days of flowering'. He, therefore, found that frequent irrigations after the appearance of first flower were conducive to earlier crop.

The correlation between the amount of water applied and the number of flowers produced, between the number of flowers opened and the bolls produced and between the number of flowers and the final yield obtained have been worked out for different years and are given in Table II.

TABLE II

Correlation between watering, flowering, bolling and yield

Year	Watering and flowering	Flowering and bolling	Flowering and yield
1928	0·472	**0·900	0·305
1929	0·379	**0·844	0·089
1930	0·034	**0·832	0·422
1931	0·447	**0·842	*0·639
1932	—0·407	**0·817	0·379
1933	0·381	0·522	0·178
1934	0·239	**0·880	0·235
1935	0·492	**0·978	*0·846
Within years . .	0·239	**0·860	**0·355

**Significant at 1 per cent level
*Significant at 5 per cent level

It may be mentioned that in working out the correlations the number of flowers and bolls have been taken only from flat beds and the yield from the entire experimental plot.

It will be seen that the quantity of water applied had no effect on the number of flowers produced. The correlations in individual years as well as that within years were all non-significant. In 1932 the correlation was negative, although non-significant. This was probably due to unusually early occurrence of frost during this year.

The correlations between flowering and bolling were all significant except during 1933. No explanation can be suggested for this deviation.

The correlations between flowering and yield in the individual years were non-significant except during 1931 and 1935, when these were significant at 5 per cent level. If, however, the results of all the years are considered together, the correlation between number of flowers and yield is significant at 1 per cent level.

Boll production. Boll counting was also done on the plants reserved for flower counting. Due to daily handling these plants were somewhat stunted, but as the effect of handling was equal in all cases the figures obtained from various treatments are comparable.

A point worth mentioning is that as the plants supplied with less water had a tendency to produce flowers earlier than those supplied with more water, it was to be expected that boll production would also be earlier in the former case. This actually happend and the 'arrival' of the crop in the beds irrigated less frequently was earlier than in those having more irrigations. In this connection the statement made by King [1922] would be of interest. He says that 'plants growing in soil which was supplied with water sparingly throughout the season produced a greater number of bolls late in the season than plants provided with larger supplies of soil moisture'. It has, however, always been found at Lyallpur that larger supplies of soil moisture tended to make the crop late.

The correlations between the amount of water applied and the number of bolls produced and between the number of bolls and the yield obtained are given in Table III.

It will be observed from Table III that the correlation between bolling and watering was non-significant in individual years, but when all the years were considered together a significantly positive correlation at 5 per cent level was obtained. This indicates that in general the number of bolls per plant is likely to be improved by the application of greater quantity of water to the crop. This fact becomes very interesting when it is considered that a large

number of irrigations did not increase flowering (Table II), but it did improve bolling. It may, therefore, be concluded that the increased quantity of water somewhat reduced the shedding percentage of bolls.

TABLE III

Correlation between watering, bolling and yield

Year	Watering and bolls	Bolling and yield
1928	0·565	0·431
1929	0·416	0·212
1930	0·463	**0·804
1931	0·300	0·584
1932	—0·287	0·619
1933	—0·429	—0·681
1934	0·600	0·618
1935	0·645	**0·918
Within years	*0·298	**0·515

**Significant at 1 per cent level
*Significant at 5 per cent level

The correlation between bolling and yield was mostly non-significant in individual years, but when the results of all the years were considered together, the correlation was significant at 1 per cent level.

It must, however, be reiterated that both the flowering and bolling records were taken on the same plants which became stunted due to constant handling [Templeton, 1932] and therefore such plants were not exactly representative of other plants in the field. But since handling of the plants was done each year and in each treatment, the number of flowers and bolls produced under different irrigation treatments can be mployed for purposes of comparison.

Yield

The yield obtained from the various treatments in different years is given in Table IV.

As types I, II and III are comparable, it may be observed that ridge sowing versus flat sowing has given indifferent results. The difference was most marked in 1931 in which ridged plots gave distinctly lower yields than the flats. Although sowing on ridges is the universal method in Egypt, this practice has been found of doubtful value in the Punjab and the extra cost of ridging the soil and dibbling the seed by hand does not seem to be justified. As regards the flat beds, type I was significantly (5 per cent level) better than both types II and III in 1930. During 1928 and 1933, type I gave better results than type II, though the difference in yield was statistically significant only in the latter year. The difference in yield between type II and type III, however, was not significant in both these years. During 1929 and 1935, both types I and II, though equal in themselves, were significantly better than type III. During 1931, type I was significantly better than type III while the difference in the yield of type II and type III was not significant. The year 1932 was rather peculiar in that during this year type I irrigation, in which the greatest quantity of water was applied, gave the lowest yield. This was, probably, due to the occurrence of early frost in this season. The opening of bolls in beds which received this treatment was somewhat delayed

TABLE IV

Tabulated yields in lb. per acre of watering experiment

Types	1928	1929	1930	1931	1932	1933	1934	1935	Average 1928-35
I Flat	444	1029	1603	892	845	1581	1366	823	1072
I Ridge	465	1078	1522	778	916	..	..	..	952
II Flat	339	920	1044	885	1100	1339	1259	823	964
II Ridge	368	1000	1087	711	978	..	..	..	829
III Flat	382	709	1058	781	1031	1399	1128	445	867
III Ridge	371	799	1006	599	1027	..	..	..	760
IV Flat	751	1139	1624	919	1153	1491	1811	1210	1262
V	..	..	1339	875	1276	1358	1559	1112	1253
VI	..	..	1250	796	1043	1402	1497	976	1161
VII	451	921	1336	828	922	1389	1511	1005	1165
Standard error	±60	±67	±78	±36	±77	±77	±100	±93	
Critical Mean difference 5 %	141·900	158·455	176·436	81·432	174·174	188·419	244·700	227·571	
1 %	209·940	234·433	253·500	117·00	250·250	285·439	370·700	344·751	

and frost did more damage to the crop in these beds as compared to the beds which had received less water and were, therefore, earlier in ripening.

On the average of eight years, it may be said that the crop which was irrigated after every three weeks gave heavier yield than the crop irrigated after longer intervals.

Type IV is a class by itself. Heaviest yield was usually recorded in this type.

Types V, VI and VII are again comparable. The differences in yield in these types were non-significant in all years except 1932 when type V was better than both types VI and VII. There was no difference between types VI and VII, showing thereby that no irrigation after the middle of October was required by the crop.

Statistical study by means of the analysis of variance and covariance of the amount of water applied and the yield obtained showed that the yield was, in general, correlated with the amount of water applied to the crop. The data are given in Table V.

TABLE V

Analysis of covariance

Year	D. F.	Sum of squares of yield	Sum of products	S. S. for water	Correlation
1928	7	120667·87	3879·28	128·84	**0·984
1929	7	143465·87	4303·22	157·12	**0·907
1930	9	505574·90	5147·16	90·36	*0·762
1931	9	85032·40	2025·28	157·16	0·580
1932	9	142304·90	1406·47	265·18	0·221
1933	6	43041·43	2017·96	215·45	0·663
1934	6	296307·70	6297·61	155·72	**0·927
1935	6	375465·70	7407·00	213·76	**0·827
Within years	59	1711860·77	32483·98	1383·59	**0·668

**Significant at 1 per cent level
*Significant at 5 per cent level

It will be seen from Table V that the coefficients of correlation between the amount of water applied and the yield obtained were non-significant during 1931, 1932 and 1933. A possible explanation for this is that the rainfall was very high during 1931 and 1933 (Table I) and the differential effect of the varying number of irrigations was masked. In 1932, on the other hand, the frosts occurred very early and the beds which had received larger quantities of water, being late in maturing, suffered more. This had an equalizing effect on the yields obtained from various beds and, therefore, the correlation coefficient between the amount of water applied and the yield obtained was non-significant. It may, however, be stated that, within the limits of the present experiment, high yields were usually obtained by applying larger quantities of water.

TECHNOLOGICAL TESTS

(*a*) *Fibre and spinning tests.* The samples of P.-A. 4F raised in the four seasons 1932-36 with different treatments of irrigation were tested at the Technological Laboratory for mean fibre-length, fibre-weight per inch and percentage of mature, half-mature and immature fibres. They were furthermore spun into suitable counts, and the yarns obtained were tested for lea breaking strength, single thread strength, yarn evenness and number of neps per yard. The methods employed in carrying out these tests as well as the number of tests made in each case have already been described by one of us [Ahmad, 1933]. The results of these tests have been summarized in Table VI.

We can draw a number of interesting conclusions by comparing among themselves the values given in Table VI of the various fibre properties of the samples or their spinning performance. However, as the same treatment was given to these samples for four successive seasons, we are in a position to apply the analysis of variance and covariance to the experimental data, which would give the correlation coefficients between the various characters as well as the critical differences by means of which we may judge the significance or non-significance of the observed differences. These calculations are shown in Table VII while Table VIII shows the mean values for the four seasons of each fibre property and the spinning performance together with the relative critical differences for $P = 0{\cdot}05$. Before we consider each property separately, we will offer a few general remarks on the extent and significance of variations observed in them. It will be noticed, from a comparison of the variance shown

TABLE

Fibre and spinning test results

Type of irrigation	No. of irrigations				Total amount of water received (in.) (Irrigation and rainfall)				Fibre-length (in.)				Fibre-weight per inch (10^{-6} oz.)			
	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36
I	7	1	6	7	26·8	31·1	23·5	24·7	0·76	0·76	0·84	0·79	0·160	0·158	0·137	0·151
II	5	4	5	5	21·0	25·0	20·5	18·7	0·77	0·74	0·80	0·80	0·156	0·142	0·148	0·156
III	4	4	4	4	18·7	25·0	17·6	15·4	0·77	0·73	0·76	0·76	0·143	0·139	0·153	0·156
IV	10	9	9	10	36·0	40·0	32·4	33·6	0·79	0·79	0·83	0·84	0·176	0·129	0·149	0·150
V	7	4	7	7	26·8	25·2	26·4	24·6	0·78	0·77	0·82	0·80	0·153	0·136	0·154	0·157
VI	8	5	8	8	29·8	27·9	29·4	27·6	0·78	0·76	0·81	0·83	0·148	0·144	0·153	0·128
VII	6	3	6	6	23·9	22·0	23·3	21·5	0·78	0·77	0·81	0·82	0·143	0·145	0·153	0·141

TABLE

Analysis of variance and covariance

Source of variation	Degrees of freedom	Sum of squares					
		Total amount of water received (in.)	Fibre Length (in.)	Fibre-weight 10^{-6} oz./in.	Maturity per cent	Standard hair wt. 10^{-6} oz./in.	H.S.W.C
1932-33	6	198·2771	0·000571	0·00080286	171·43	0·00071743	4·8571
1933-34	6	215·4543	0·002400	0·00048286	100·86	0·00052371	3·3571
1934-35	6	155·7143	0·004000	0·00023286	136·86	0·00035143	14·8571
1935-36	6	213·7543	0·004371	0·00066971	13·71	0·00099886	41·8571
Total (within seasons)	24	783·2000	0·011342	0·00218829	422·86	0·00259143	64·9284
Between 7 irrigation types	6	706·5886	0·007671	0·00023236	135·93	0·00031436	27·6250
Error	18	76·6114	0·003671	0·00195593	286·93	0·00227707	37·3034

VI

of P.-A. 4F. 1932-36

Maturity (per cent)				Standard hair-weight 10^{-6} oz.				Total loss (pe cent)				Neps per yard				Highest standard warp counts			
32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-33	33-34	34-35	35-36	32-38	33-34	34-35	35-36
44	61	33	46	0·194	0·170	0·168	0·174	17·7	16·8	19·4	18·4	0·9	0·6	0·7	0·9	24	23½	30½	26
41	53	34	47	0·192	0·162	0·181	0·178	16·1	16·9	18·7	18·4	0·7	0·9	1·2	1·1	23½	22½	29½	24½
49	49	35	47	0·169	0·164	0·189	0·180	16·2	17·0	19·1	18·6	0·9	1·6	1·4	1·0	24	24	29½	21½
52	60	44	47	0·202	0·141	0·173	0·174	15·2	16·5	19·1	18·0	1·0	1·6	0·6	0·6	25½	22	34	28
43	57	40	46	0·188	0·153	0·180	0·177	16·7	17·8	18·3	17·3	1·4	1·3	1·2	1·3	24½	23	32	29
36	57	42	49	0·191	0·158	0·176	0·143	17·5	16·6	18·4	17·2	1·1	0·8	0·4	0·9	26	23	31½	28½
41	56	32	44	0·178	0·162	0·188	0·165	17·8	17·8	18·9	17·2	1·1	0·6	0·7	1·2	25	22	31	27

VII

of P.-A. 4F. 1932-36

Sum of products					Correlation coefficient				
1·2	1·3	1·4	1·5	1·6	r_{12}	r_{13}	r_{14}	r_{15}	r_{16}
0·21129	0·294457	33·8887	0·296186	22·7571	0·628	0·738	0·184	*·0785	0·733
0·42200	−0·098771	90·5714	−0·206914	-5·9214	0·587	−0·303	0·614	−0·616	−0·220
0·53200	−0·002471	121·0715	−0·137457	44·6714	0·674	−0·013	*0·829	−0·588	**0·929
0·78986	−0·138186	2·7143	−0·167429	74·8286	*0·817	−0·365	0·050	−0·362	*0·791
1·95515	0·055029	248·2429	−0·15614	136·3357	**0·656	0·042	*0·431	−0·151	*0·605
2·01093	0·053436	275·3036	0·238711	116·5000	*0·864	0·132	**0·888	−0·507	*0·834
−0·05578	0·001593	−27·0607	0·023097	19·8357	−0·105	0·004	−0·183	0·055	0·37

* Significant at 5 per cent level
* Significant at 1 per cent level

TABLE VIII

Fibre and spinning test results of P.-A. 4F. (mean values, 1932-36)

Type of irrigation	Mean for four seasons 1932-36					
	Amount of water received (in.)	Fibre length (in.)	Fibre weight per inch (10^{-6} oz.)	Mature hairs (per cent)	Standard hair weight (10^{-6} oz.)	H. S. W. Counts
I	26·52	0·788	0·152	46·0	0·1765	26·0
II	21·30	0·778	0·150	43·8	0·1783	25·0
III	19·18	0·755	0·148	45·0	0·1755	24·8
IV	35·50	0·812	0·151	50·5	0·1725	27·4
V	25·75	0·792	0·150	46·5	0·1745	27·1
VI	28·68	0·795	0·143	46·0	0·1670	27·2
VII	22·68	0·795	0·146	43·2	0·1733	26·2
Grand mean	25·66	0·788	0·149	45·9	0·1739	26·2
Critical difference for $P = \cdot 05$		±0·021	±0·015	±5·93	±0·0167	±2·1

in the last two rows of Table VII that, except in the case of mean length, the variation was not significant even for 5 per cent level of significance for the other characters. This being the case, it follows that the variation produced by different amounts of irrigation in fibre weight per inch, maturity, standard hair weight or the spinning performance of this cotton was quite small. If as a result of further analysis we observe any positive correlation between the amount of irrigation and any of these properties, either for a single season or for the mean of four seasons, it should be taken to indicate only a trend which may be due to the operation of the variable irrigation factor or may be due to random causes.

We shall now consider each property separately.

(*b*) *Mean fibre length*. It will be seen from Table VII that only in one season, namely 1935-36, the correlation between the amount of water and the mean fibre length was significant, being non-significant, though positive in the other seasons. However, the correlation coefficient for all the seasons between the total amount of water applied and the mean fibre length of the cotton is positive and significant, showing that, in general, the application of more water during the growth period is likely to improve, to a very small extent, the mean fibre length of this cotton. This result is borne out by the mean values given in Table VIII, which show that the highest value is associated with the largest amount of water received by the crop, while it tends to decrease as less and less water is applied to it. This is especially the case for types I-IV. Apart from type IV, which entailing a large quantity of water, may not always prove a practical proposition, it will be noticed that type I gave, on the whole, significantly better results than type III, showing that irrigation after every three weeks might be conducive to the development of slightly longer fibres as compared with irrigtion after every five weeks. The difference between types II and III shows that from the point of view of staple length irrigation after every four weeks might be bettter than irrigation after every five weeks.

(*c*) *Fibre weight per inch*. The values of the correlation coefficients between the amount of water applied and the fibre weight per inch show that neither in any individual season nor for all the seasons taken together the amount of water had any significant effect upon the fibre weight per inch of this cotton. We may thus conclude that so far as the cultivation of this cotton under the conditions prevailing at Lyallpur is concerned the amount of water applied to the crop, within the limits of this experiment, did not produce any significant effect upon its fibre weight per inch.

(*d*) *Fibre maturity*. The correlation coefficient between the amount of water received by the crop and the percentage of mature hairs is positive in all the seasons, but only in one season, namely 1934-35, it is significant. If we take the results for all the seasons together, we find that the correlation coefficient between the percentage of mature hairs and the amount of water applied to the crop is positive and significant, showing that, in general, a tendency exists for this cotton to develop a higher percentage of mature fibres if more irrigation is given to the crop. This is also shown by the mean values given in Table VIII. It will be noticed that type IV, which represented the highest amount of irrigation, gave the largest

percentage of mature hairs, while among the other types, this percentage showed a tendency to decrease as less water was given to the crop. The difference between types IV and II is significant, while the other differences are non-significant. It will be further noticed that the zemindari types did not show any significant differences either among themselves or from the other types except type VII which gave significantly lower percentage of mature hairs as compared with type IV.

(e) *Standard hair weight.* Since the values of the fibre weight per inch and the percentages of mature, half-mature and immature fibres were available, the standard hair weight was calculated according to the following formula given by Peirce and Lord [1934], and statistical analysis was applied to it.

$$\text{Standard hair waight} = \frac{88.9\ W}{M + 0{\cdot}75\ H.M. + 0{\cdot}45\ I}$$

Where :

W = fibre weight per inch

M = mature hairs (per cent)

$H.\ M.$ = half mature hairs (per cent)

I = immature hairs (per cent)

The values of correlation coefficients given in Table VII show that with the exception of one season, namely 1932-33, the correlation coefficient between the amount of water applied and the standard hair weight is negative and non-significant. In 1932-33, however, this value is found to be positive and significant, which is rather unusual. On examining the individual values for this season, we notice an abnormally high value of fibre weight per inch for type IV. If this single value is omitted, the correlation coefficient ceases to be significant. It is therefore probable that this positive and significant correlation is due to this single value, although this point cannot be definitely decided on the basis of the present data. However, if we take the results for all the four seasons together, we find that, as in the case of fibre weight per inch, the correlation coefficient between the amount of water applied and the standard hair weight is non-significant, showing that the different irrigations tried in these experiments have no significant effect upon the standard hair weight of P.-A. 4F when grown under conditions normally prevailing at Lyallpur.

(f) *Neps per yard.* In view of the fact that neps are adjudged by the eye and that some of the small neps lying within the yarn may escape detection, a certain amount of subjective error is involved in the estimation of this yarn property. We have not, therefore, thought it necessary to apply the analysis of variance to it ; but, it will be noticed that, on the whole, the number of neps per yard is slightly higher for types III and V than for the other types and that among the latter the differences are quite small.

(g) *Highest standard warp counts.* It will be seen from Table VII that only in one season, namely 1933-34, the correlation between highest standard warp counts and amount of water was negative, while in the remaining three seasons, it was positive. Furthermore, if we take the results for all the seasons together, the correlation coefficient is positive and significant, showing that, in general, a tendency exists for this cotton to give better performance if more water is applied to the crop. This result is also brought out by the mean values given in Table VIII. It is interesting to note that two variations of the zemindari treatment compare quite favourably in respect of spinning performance with type IV, which represented the highest amount of irrigation, while the zemindari treatment compared quite favourably with type I in this respect.

Discussion

The results of eight years' watering experiment on Punjab-American 4F at the Cotton Research Farm, Risalewala, where the quantity of water applied at each irrigation was accurately measured, have been described. Certain features of these experiments are contrary to what has already been found elsewhere and it will be interesting to try to find out the causes of such discrepancies.

King [1922] has found in Arizona that heavily watered beds produced the majority of the flowers 'during the first 45 days of flowering' and that heavy irrigations were conducive to an earlier crop. Reverse was found to be the case at Lyallpur, as the heavily watered beds were later in maturity as compared to those where water was applied sparingly. King was experimenting with the Americo-Eygptian cotton Pima, whose habit of growth is different from the Punjab-American 4F. Moreover, the climatic conditions of Phoenix (Arizona) and Lyallpur are also vastly different as will be seen from Table IX.

Although it is recognized that the mean monthly normal temperatures are not to be relied upon in plant physiology studies, yet Table IX gives a bird's eye view of the differences in the climatic conditions of the two places. The weather at Lyallpur is much more severe during the growth and flowering season of cotton than the weather at Phoenix and the heavier and more frequent irrigations are helpful in keeping the plants in normal healthy condition at the former place. Shortage of water during this stage is likely to be far more disastrous at Lyallpur than at Phoenix. In Lyallpur the super-imposed condition of non-dehiscence of anthers [Trought,

TABLE IX

Mean monthly normal temperatures

	Phoenix, Arizona	Lyallpur	Giza, Egypt
January	51·2	53·3	51·6
February	[illegible]	[illegible]	[illegible]
March	[illegible]	[illegible]	[illegible]
April	[illegible]	[illegible]	[illegible]
May	[illegible]	[illegible]	[illegible]
June	[illegible]	[illegible]	[illegible]
July	[illegible]	[illegible]	[illegible]
August	[illegible]	[illegible]	[illegible]
September	[illegible]	[illegible]	[illegible]
October	[illegible]	[illegible]	[illegible]
November	[illegible]	[illegible]	[illegible]
December	52·6	55·6	54·9
Annual	69·7	75·4	67·1

1928] has also to be taken into account. Due to lack of pollination most of the flowers produced on all Punjab-American cottons till about the end of August each year are shed. Thus the effective flowering begins from the month of September. This condition does not exist in Phoenix where the early-formed flowers are most effective. Moreover, at Phoenix, most of the early-formed flowers, especially in beds receiving copious irrigations where shedding of bolls due to shortage of water is very slight, are matured into bolls with the result that the 'arrival' of the crop in such beds is earlier than in beds receiving less water.

Another instance is provided by ridged beds. As has already been said above, sowing on ridges is the universal method in Egypt, but this method has not proved useful at Lyallpur. The reason for this is not far to seek. The Egyptian soil is much heavier than the Lyallpur soil and germination is likely to be very defective on heavy soil without the aid of ridging. Mid-March is the optimum time of sowing near about Cairo. In upper Egypt sowings are now generally done in February. Sowing on the north side of ridges is universally practised. In Lyallpur, on the other hand, the sowings are usully done from 15 May to 15 June when the weather is very hot (Table IX) and ridged soil dries up within a few days. It is our experience that when sown on ridges the first three waterings should be given within the first month after sowing. If this is not done the 'stand' of the crop remains very poor and the yield proportionately reduced. Such huge quantities of water are not available in the Punjab and, therefore, sowing on ridges is not profitable. The Lyallpur soil is loamy and very friable and flat sowing usually results in excellent germination. In Egypt, cotton usually receives eight to eleven irrigations [Crowther, Tomforde and Mahmoud, 1937] as against five or six in Lyallpur. Frequent irrigations are absolutely necessary in the case of ridge sowing as will also be clear from Table [illegible]. The average yield of ridged beds was [illegible], [illegible] and 761 lb. per acre in types I, II and III, respectively. Thus, by lengthening the interval between irrigation the effect on the yield was disastrous. The Punjab farmers cannot afford to apply frequent irrigations to their cotton crop and hence ridging is not a method which can be recommended to them. Balls and Holton [1915] have mentioned an interesting case wherein it is emphasized that large quantities of water should be applied at each irrigation to ridged plots in order to obtain the maximum yield. They have mentioned that instead of 'running water into groups of ten ridges at a time in the usual way and then closing them off to proceed to the next set of ten, we opened up 50 ridges at once, and turned the same flow of water into them. In this way a much greater quantity of water is given since the soil has time to absorb more of water'. In view of the general prevailing conditions in the Punjab, sowing on ridges may therefore be ruled out as an alternative to flat sowing.

We may now compare the results of technological tests with those found by earlier workers with other varieties of cotton. The earlier observations on the effects of irrigation on the fibre properties and the spinning performance of cotton are comparatively few. Mayton and others [1931] found, with reference to cottons grown in the Mississippi delta, that length of lint and size of boll were influenced by soil moisture, short lint being associated with low moisture content in the soil from 1 to 15 days after the appearance of the flowers. This observation agrees in general with our result that the lint length is positively correlated with the amount of irrigation applied to the crop. Sturkie [1934] made a detailed study of the influence of soil type, climatic conditions and soil moisture on the development of lint and seed in cotton. He found that, out of these factors, the amount of available moisture in the soil was the only one which influenced the development of lint in cotton. From his observations he concluded that low moisture content caused short lint to be formed, and that it was possible to reduce the length of lint by at least 1/8 in. by reducing the soil moisture to a critical point. This result also agrees, it will be noticed, with our observations on P.-A. 4F. This problem was attacked from a different angle by Koshal and Ahmad [1937]. They utilized the extensive data available for the standard Indian cottons and applying to it Fisher's [1934] method of fitting the polynomials, evaluated the effect of rainfall sequence upon lint quality. They found that rainfall is an important weather-element,

which may account for ½ to ⅓ of the total variation in quality of cotton, that in the maturation period it is generally beneficial, while in the growing period it may be beneficial in the case of some cottons and harmful for others, and that even for the former cottons it is beneficial only in the first half of the growing period. These conclusions agree in a general way with the results of the present investigation: but it is not possible to push the comparison further, partly because the statistical analysis was not applied to the Punjab cottons owing to the paucity of relevant data and partly because, in the present investigation, we are considering the effect of additional irrigation, which is not exactly equivalent to additional rainfall. The effect of differential irrigation on the field behaviour and quality of Cambodia Co 2 cotton has been studied by one of us in collaboration with Ramanatha Ayyar and Thirumalachari [1940]. Statistical analysis was not applied to the fibre-test results but it was noted that while the mode of irrigation did not affect the mean fibre length of this cotton, it influenced the fibre weight per inch, which showed a tendency to increase with the amount of water applied to the crop. The strength of the yarns was slightly less for the irrigated than for the unirrigated samples, and these small differences were attributed to the increase in fibre-weight per inch with irrigation. It will be noticed that the results for Cambodia Co 2 are in some respects different from those obtained for P.-A. 4F, which was found to improve slightly in length and spinning performance with the amount of irrigation. This differential behaviour is no doubt connected with the type and texture of the soils in the two areas and with the climatic conditions prevailing at the two places in the growing and maturation periods. It indicates the desirability of exercising caution in making general statements regarding the response of cottons to agronomical factors and the necessity of carrying out well-designed experiments in areas differing in respect of soil and climate.

Summary

The results of irrigation experiment on Punjab-American 4F involving seven different types of irrigation have been discussed. Flowers and bolls produced per plant were not correlated with the quantity of water given to the crop: but, in general, the yield was correlated with watering. Ridging versus flat sowing gave indifferent results.

Application of more water during the growing period is likely to improve, to a small extent, the mean fibre length of P.-A. 4F. The amount of irrigation applied to the crop did not produce any significant effect either on the mean fibre weight per inch or the standard hair weight of this cotton. The percentage of mature hairs in P.-A. 4F showed a tendency to increase with the amount of water applied to the crop.

The spinning performance of this cotton showed a small tendency to improve as more water was given to the crop. It is noteworthy in this connection that the zemindari system of irrigation and its two variants compared favourably in respect of spinning performance of the lint with the type which represented the highest amount of irrigation.

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BASE-EXCHANGE STUDIES

II. VARIATION IN THE CONTENT OF EXCHANGEABLE BASES AFFECTING PLANT GROWTH

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(With Plate XV and three text-figures)

In a previous communication, Singh and Nijhawan [1936] published the results of a preliminary investigation on the effect of different cations on the physico-chemical properties of the soil on the one hand, and their relationship to plant growth on the other. The study was primarily of a qualitative nature, and the influence of single bases saturating the soil's exchange complex was determined on wheat crop. The investigation though of fundamental importance did not furnish sufficient data which might solve the problem from the practical point of view, the reason being that these clays prepared in the laboratory did not represent true condition of soil in the field. For instance, a soil may contain calcium or sodium as a predominating exchangeable base, but it is not likely to meet under field conditions such extreme cases of soil which may behave in the same manner as calcium or sodium saturated soils prepared artificially. The same applies to soils saturated with other cations. Therefore, the present investigation was undertaken with a view to throw further light on this problem, and to study the effect of varying amounts of exchangeable bases under different conditions so as to bring into the scope of this investigation such types of soil as might occur under field conditions with respect to various cations.

The importance of exchangeable bases in the soil fertility has been fully realized, and a large amount of research work has been carried out during the past quarter of a century on the nature and properties which these bases confer on the soil's exchange complex by virtue of their presence in it, but little work of any importance has been done on the effect of these bases on plant growth. This is mainly due to the fact, that the preparation on a bulk scale of these clays containing varying amounts of exchangeable bases is not only an expensive but extremely laborious and tedious operation. The uptake of mineral salts by plants has been studied in great detail in water-culture solutions, but the conditions in soil, owing to its colloidal nature are entirely different, and the amount of salts that are rendered available to the plant under these conditions vary considerably. Therefore, it is of utmost importance to determine the amount of plant food material removed by the crop from soils containing varying amounts of exchangeable bases.

Experimental

Soil from the first foot stratum of an average field on the Lyallpur Agricultural Farm was obtained for the purpose of this investigation. The bulk sample, after being dried in the air, was powdered and sieved through a 2-mm. sieve. On analyses it gave the following results (Tables I—IV) :

Table I

Mechanical analysis (per cent on air-dried soil)

Clay 0-0·002 mm.	Silt 0·002-0·02 mm.	Fine sand 0·02-0·2 mm.	Sand 0·2-2·0 mm.	Gravel above 2 mm.	Total carbonates ($CaCo_3$)
17·03	21·44	43·57	15·87	0·09	1·51

Table II

Analysis of HCl extract (per cent on air-dried soil)

Insoluble residue	Soluble silica	Iron (Fe_2O_3)	Aluminium (Al_2O_3)	Sodium (Na_2O)
82·56	0·11	5·00	4·36	0·21

Potassium (K_2O)	Calcium (CaO)	Magnesium (MgO)	Phosphorus (P_2O_5)
1·71	1·80	1·25	0·14

Table III

Analysis of citric acid extract, organic matter and total nitrogen (per cent on air-dried soil)

Potassium (K_2O)	Phosphorus (P_2O_5)	Organic matter	Total Nitrogen (N)
0·048	0·063	0·350	0·0308

TABLE IV

Exchangeable bases (milli-equivalents per cent)

Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Base exchange capacity
0·62	0·64	4·52	0·86	6·66

From the bulk sample, soils saturated with various cations were prepared by exhaustively leaching the soil with neutral chloride solutions of the respective cations [Singh and Nijhawan, 1936]. Sodium, potassium, calcium and magnesium soils thus obtained were thoroughly mixed with the original soil in the proportions given in Table V, so as to obtain soils containing varying amounts of exchangeable bases.

TABLE V

Plan of experiment

Soil series	Pot Nos.
A—Sodium group	
1. 100 per cent sodium clay . . .	1—4
2. 75 per cent Na clay and 25 per cent soil .	5—8
3. 50 per cent Na clay and 50 per cent soil .	9—12
4. 25 per cent Na clay and 75 per cent soil .	13—16
B—Potassium group	
5. 100 per cent potassium clay . . .	17—20
6. 75 per cent K clay and 25 per cent soil .	21—24
7. 50 per cent K clay and 50 per cent soil .	25—28
8. 25 per cent K clay and 75 per cent soil .	29—32
C—Calcium group	
9. 100 per cent calcium clay . . .	33—36
10. 75 per cent Ca clay and 25 per cent soil .	37—40
11. 50 per cent Ca clay and 50 per cent soil .	41—44
12. 25 per cent Ca clay and 75 per cent soil .	45—48
D—Magnesium group	
13. 100 per cent magnesium clay . .	49—52
14. 75 per cent Mg clay and 25 per cent soil	53—56
15. 50 per cent Mg clay and 50 per cent soil	57—60
16. 25 per cent Mg clay and 75 per cent soil	61—64
17. Original soil	65—68

350 gm. of the mixed soils thus prepared were filled according to the above plan in pots each measuring 11 cm. in diameter and 9 cm. in height, and fitted with a glass tubular near the bottom for aeration. In all 68 pots were prepared in this manner, which gave four repeats of each treatment. In order to guard against any deficiencies in the essential plant food materials, a mixture of potassium nitrate, ammonium nitrate and single superphosphate, containing 0·1315 gm. of nitrogen, 0·1315 gm. of potash and 0·0658 gm. of phosphoric acid was applied to each pot.

The pots were placed in a wire-gauze cage, and were given identical cultural treatments. After sowing with wheat they were sprayed with water from time to time in order to maintain the requisite amount of moisture in them. It was observed that only a small amount of water was absorbed by soils treated with sodium and potassium salts, and the bulk of it evaporated from the surface. To safeguard against desiccation, an additional quantity of water was added from time to time.

ANALYSIS OF THE SOILS

Exchangeable bases and pH values were determined in soils prepared for the pot experiments, and the results are depicted in Table VI. Exchangeable bases have been shown both as milli-equivalents per 100 gm. of the soil and as percentages of the total bases. A reference to this table shows that there is a regular gradation in the content of exchangeable bases placed under different groupings. When we consider the exchangeable base content of saturated soils only, we find that the displacement of bases does not take place completely, and it varies with the nature of the cations. The maximum displacement occurs in the case of calcium (98·04), and this is followed by sodium (94·14), magnesium (88·24) and potassium (86·09).

The pH values of these soils (Table VI) clearly indicate that the nature and the amount of cations in the exchange complex greatly affect the reaction of the soil. The soils containing monovalent cations have higher pH values than those having divalent cations. Further, the sodium group has a higher pH value than the potassium group in the monovalent series, and the magnesium group has higher value than the calcium group in the divalent series.

Differences in the pH values due to variation in the amount of exchangeable bases are depicted in Table VII.

It will be observed that a change in the amount of exchangeable sodium brings about a great variation in the pH values, as compared with a corresponding change in other groups. The variation is somewhat less in case of potassium, still less in magnesium and hardly any in calcium treated soils,

TABLE VI

Exchangeable bases and pH values

Soil series	Exchangeable bases *m. eq.* per 100 gm. of soil					Relative proportion of bases in *m. eq.* expressed as percentage of total bases				pH values
	Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	Total	Sodium Na	Potassium K	Calcium Ca	Magnesium Mg	
A—Sodium group										
1. 100 per cent sodium clay	6·200	..	0·310	0·075	6·585	94·14	..	4·71	0·14	9·99
2. 75 per cent Na clay and 25 per cent soil	4·866	0·161	1·420	0·267	6·714	72·47	2·40	21·15	3·98	9·68
3. 50 per cent Na clay and 50 per cent soil	3·520	0·330	2·420	0·478	6·748	52·24	4·90	35·92	7·09	9·14
4. 25 per cent Na clay and 75 per cent soil	2·007	0·502	3·480	0·681	6·670	30·09	7·53	52·17	10·19	7·97
B—Potassium group										
5. 100 per cent potassium clay	0·170	5·616	0·620	0·117	6·523	2·60	86·09	9·50	1·79	9·49
6. 75 per cent K clay and 25 per cent soil	0·272	4·397	1·520	0·321	6·510	4·17	67·56	23·35	4·93	8·92
7. 50 per cent K clay and 50 per cent soil	0·387	3·010	2·460	0·499	6·356	6·09	47·35	38·69	7·84	8·35
8. 25 per cent K clay and 75 per cent soil	0·492	1·860	3·340	0·686	6·378	7·71	29·17	52·37	10·75	7·82
C—Calcium group										
9. 100 per cent calcium clay	..	0·039	6·550	0·092	6·681	..	0·58	98·04	1·37	7·43
10. 75 per cent Ca clay and 25 per cent soil	0·153	0·199	6·000	0·285	6·637	2·30	3·00	90·38	4·29	7·44
11. 50 per cent Ca clay and 50 per cent soil	0·301	0·345	5·500	0·470	6·616	4·56	5·21	83·10	7·10	7·43
12. 25 per cent Ca clay and 75 per cent soil	0·459	0·416	5·020	0·669	6·564	6·99	6·33	76·48	10·19	7·43
D—Magnesium group										
13. 100 per cent magnesium clay	0·053	0·089	0·640	5·875	6·657	0·80	1·33	9·61	88·24	8·35
14. 75 per cent Mg clay and 25 per cent soil	0·196	0·263	1·520	4·603	6·582	2·98	4·00	23·09	69·94	8·14
15. 50 per cent Mg clay and 50 per cent soil	0·343	0·413	2·400	3·341	6·497	5·27	6·36	36·94	51·42	7·92
16. 25 per cent Mg clay and 75 per cent soil	0·482	0·519	3·420	2·104	6·525	7·38	7·96	52·42	32·24	7·71
17. 100 per cent original soil	0·622	0·642	4·520	0·861	6·645	9·36	9·67	68·03	12·95	7·43

TABLE VII

Differences in the pH values due to variation in the amount of exchangeable bases

*p*H range	Sodium group 7·43-9·99	Potassium group 7·43-9·49	Calcium group 7·43-7·44	Magnesium group 7·43-8·55
Differences amongst				
100 per cent and 75 per cent treated	0·31	0·57	—0·01	0·21
75 per cent and 50 per cent treated	0·54	0·57	0·01	0·22
50 per cent and 25 per cent treated	1·17	0·53	0·00	0·21
25 per cent treated and original soil	0·54	0·39	0·00	0·28
Average *p*H difference	0·64	0·52	0·00	0·23

Analysis of citric acid extract

The analysis of the citric acid extract of the saturated soils (Table VIII) shows that the available potash is greatly reduced in the calcium and sodium saturated soils as compared with the original soil.

TABLE VIII

Analysis of citric acid extract of soils saturated with different cations

	Potassium (K_2O)	Phosphorus (P_2O_5)
Sodium-saturated soil	0·028	0·062
Potassium-saturated soil	0·314	0·060
Calcium-saturated soil	0·027	0·058
Magnesium-saturated soil	0·034	0·067
Original soil	0·048	0·063

These data lead to the following two conclusions: (*a*) That a large proportion of the citric-soluble potassium is formed by the exchangeable potassium ions that surround the clay particles; (*b*) The amount of available potash of the soils saturated with different cations is in the same order as their absorption capacities, viz. Ca>Na>Mg.

A reference to the data of available phosphoric acid shows that its amount is reduced in the case of calcium-saturated soil, while in the case of soils saturated with other cations it is almost equal to that present in the original soil.

Physiological characteristics of wheat crop

Wheat grains (8A) treated with hot water against loose smut were employed. Seeds of uniform size, weight and shape of kernal were selected, and soaked in distilled water for about 16 hours at room temperature. Five of these grains were sown in each pot in the first week of December at a uniform depth of one inch.

Germination

Germination started on the sixth day after sowing, and all the seeds germinated by the eighth day except in the case of 75 per cent sodium, 100 per cent and 75 per cent potassium pots where the number of days required for complete germination was nine. In 100 per cent sodium clay, however, germination started on the seventh day, and was complete by the eleventh day after sowing. Cent per cent germination was recorded in all the pots, but the adverse effect of sodium clay was noticeable by its retarding influence on germination.

Growth

A fortnight after sowing, only three plants of more or less uniform size were retained in each pot. Tillering was observed in the first week of January. The plants were healthy and strong in all the pots. They commenced to head out in the beginning of March and continued to flourish up to the time of harvesting, and yielded healthy and well-developed grains except in the sodium soils. In sodium-saturated soil, however, no seed formation occurred, and the crop was very poor. A somewhat similar conclusion was arrived at by Ratner [1935] who studied the effect of varying amounts of exchangeable sodium on plant growth.

Observations on the growth, height, and number of tillers per pot under different series were made, and the results are summarized in Table IX.

Table IX

Growth and yields of wheat crop

	Growth of wheat crop		Yield of wheat crop (gm.)		
	Average height of plants (in.)	Average No. of tillers per pot	Total yields	Straw	Grain
A—Sodium group					
1. 100 per cent sodium clay	6·68	7·75	3·90	3·90	..
2. 75 per cent Na clay and 25 per cent soil	7·84	13·50	5·80	5·00	0·80
3. 50 per cent Na clay and 50 per cent soil	9·00	12·75	6·80	5·38	1·42
4. 25 per cent Na clay and 75 per cent soil	8·88	26·25	7·22	5·57	1·65
B—Potassium group					
5. 100 per cent potassium clay	8·46	15·25	6·20	5·10	1·10
6. 75 per cent K clay and 25 per cent soil	9·89	22·75	6·90	5·65	1·25
7. 50 per cent K clay and 50 per cent soil	9·79	27·25	7·25	5·80	1·45
8. 25 per cent K clay and 75 per cent soil	9·20	26·75	7·55	6·30	1·25
C—Calcium group					
9. 100 per cent calcium clay	18·84	39·50	12·50	10·10	2·40
10. 75 per cent Ca clay and 25 per cent soil	14·96	36·00	10·62	8·25	2·37
11. 50 per cent Ca clay and 50 per cent soil	12·96	33·00	8·80	6·70	2·10
12. 25 per cent Ca clay and 75 per cent soil	10·29	25·75	7·80	5·90	1·90
D—Magnesium group					
13. 100 per cent magnesium clay	12·04	26·00	8·17	6·97	1·20
14. 75 per cent Mg clay and 25 per cent soil	11·92	28·25	7·80	6·75	1·05
15. 50 per cent Mg clay and 50 per cent soil	11·17	30·00	7·10	6·00	1·10
16. 25 per cent Mg clay and 75 per cent soil	11·29	27·00	6·54	5·44	1·10
17. 100 per cent original soil	10·96	29·25	7·70	5·90	1·80
Standard error	±0·285	±1·898	±0·161	±0·142	±0·064

Statistical examination of the data (Table X) shows that calcium and magnesium soils in high concentrations produced a very beneficial effect on heights, which in the former case was greater than in the latter. Lower concentrations (25 per cent calcium and 25 per cent magnesium), however, did not give any better results than the control, and the response to both these doses was not significant. Sodium and potassium, on the other hand, produced a harmful effect, and although in higher doses both were equally injurious to plant growth, in smaller doses the effect of sodium was more marked than that of potassium. As regards tillering, all the calcium-treated pots except 25 per cent calcium gave significant results, but none of the treatments in magnesium series proved to be effective. 25 per cent sodium, 25 per cent and 50 per cent potassium-treated pots behaved in the same manner as lower doses of magnesium, but 75 per cent sodium and 100 per cent potassium proved definitely injurious—100 per cent sodium produced the most deleterious effect.

The relative growth of wheat crop on different soils can also be observed from Plate XV.

Yields

The crop was harvested, and dried in the air. The grain and straw were weighed separately. A summary of the yield data is given in Table IX.

The statistical analyses of the total yields of wheat crop, the yields of grain and straw obtained from different soils have given the following results (Table X).

Calcium in higher doses significantly increased the yield of both total dry matter and the straw, while in lower doses (50 per cent and 25 per cent) and all doses of magnesium the differences were not significant. Taking the yield of grain separately, it was found that higher doses of calcium significantly promoted grain formation, while lower doses were without any effect. Magnesium, on the other hand, definitely and significantly reduced the yield of grain in all doses except 100 per cent magnesium where the results were not significant. Sodium and potassium bases in all doses unfavourably affected the yields of grain and straw. No significant differences were observed amongst sodium and potassium treated pots except that 25 per cent sodium yielded more of grain than 75 per cent sodium. 100 per cent sodium gave the minimum crop yield, but it was not significantly inferior to higher doses of potassium and the remaining doses of sodium in the case of yield of straw.

Analysis of crop and discussion of results

Analysis of plant material

The plant material from different soils after cleaning was dried in the sun and this was followed by drying in an electric oven (100-105° C.) for 24 hours. It was then incinerated over low flame and finally ignited in an electric muffle at a temperature not exceeding dull redness (550°C.) until the residue was almost white. The hydrochloric acid extract of the ash was prepared according to the official method of the A. O. A. C. and analyzed for sodium, potassium, calcium, magnesium and phosphoric acid.

The data of crop yields in terms of oven-dried material with its mineral composition are given in Table XI.

Table X

Analyses of variance of growth and yield data

Source of variance	D. F.	Sum of squares	Mean square	Ratio of variance	Sum of squares	Mean square	Ratio of variance
			Heights of plants			No. of tillers per pot	
Between treatments	16	530·120	33·1325	102·040	3990·030	249·375	17·303
Within treatments	51	16·560	0·3247		735·500	14·412	
Total	67	546·680	..	..	4725·530	..	..
			Total yields			Yield of wheat straw	
Between treatments	16	14·340	0·8963	8·642	7·734	0·4834	5·961
Within treatments	51	5·290	0·1037		4·134	0·0811	
Total	67	19·630	..	..	11·868	..	..
			Yield of wheat grain				
Between treatments	15	1·427	0·0951	5·799			
Within treatments	48	0·786	0·0164				
Total	63	2·213	..	..			

The high values for the ratios of variances show that the effects of treatments in all cases are highly significant

GROWTH OF WHEAT CROP AS INFLUENCED BY VARIATIONS IN THE CONTENT OF EXCHANGEABLE BASES

100% 75% 50% 25%
Sodium group

100% 75% 50% 25%
Potassium group

100% 75% 50% 25%
Calcium group

100% 75% 50% 25%
Magnesium group

Na K Ca Mg Control
100% Clay

Na K Ca Mg
75% Clay & 25% Soil

Na K Ca Mg
50% Clay & 50% Soil

Na K Ca Mg
25% Clay & 75% Soil

Ash content of plants

It will be observed that the percentage ash content of plants grown on different soils varies considerably with the nature of cations (Fig. 1). The percentage of mineral matter removed by crops grown on soils containing divalent bases is less than that removed from the monovalent bases. Amongst the divalent bases the absorption from calcium soils is much less than that from the magnesium soils, while in the case of monovalent bases there is hardly any difference in absorption from sodium and potassium soils.

In the case of sodium, potassium and magnesium soils the percentage of mineral matter increases with the increasing amounts of their respective cations in the exchange complex, but reverse is the case with calcium soils, where percentage of mineral matter is least in calcium-saturated soil. In the case of saturated soils the order of mineral matter removed is K>Na>Mg>Ca.

When, however, the total quantity of mineral matter removed by the crop is taken into consideration, the order is changed, because the presence of the different bases not only affects the percentage composition of the crop, but the total dry matter is also affected to a much greater extent, with the result that the total mineral matter removed is maximum in that soil which gives the highest yield, and therefore the order is naturally in accordance with the yields of crops, i.e. Ca>Mg>K>Na.

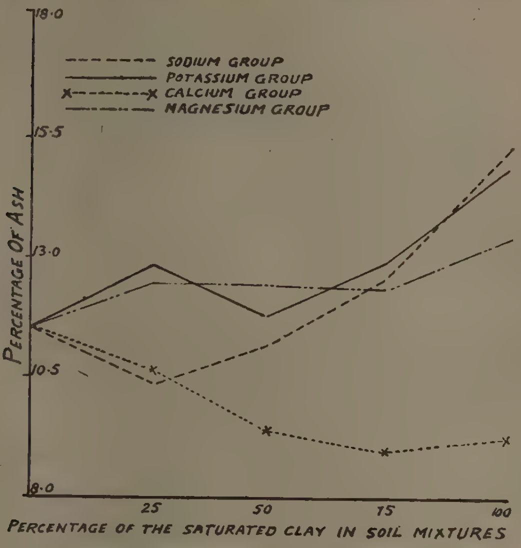

FIG. 1. Exchangeable bases and ash content of wheat crop

TABLE XI

Yield and mineral composition of wheat crop

Soil series	Average oven-dried weight per pot (gm.)	Mineral composition (per cent on oven-dried material)						
		Ash	Insoluble residue	Sodium Na_2O	Potassium K_2O	Calcium CaO	Magnesium MgO	Phosphorus P_2O_5
A—Sodium group								
1. 100 per cent sodium clay	0·85	15·300	4·841	2·200	5·630	0·388	0·347	0·475
2. 75 per cent Na clay and 25 per cent soil .	1·37	12·622	3·613	1·635	4·787	0·421	0·361	0·469
3. 50 per cent Na clay and 50 per cent soil .	1·58	11·222	3·075	1·295	3·013	0·445	0·384	0·436
4. 25 per cent Na clay and 75 per cent soil .	1·70	10·432	3·409	0·811	2·596	0·454	0·399	0·410
B—Potassium group								
5. 100 per cent potassium clay . . .	1·38	14·699	3·432	0·241	6·658	0·296	0·293	0·556
6. 75 per cent K clay and 25 per cent soil .	1·62	12·718	3·673	0·268	6·271	0·389	0·331	0·528
7. 50 per cent K clay and 50 per cent soil .	1·72	11·792	3·515	0·349	5·470	0·443	0·381	0·516
8. 25 per cent K clay and 75 per cent soil .	1·73	12·677	4·349	0·324	4·163	0·532	0·359	0·517
C—Calcium group								
9. 100 per cent calcium clay . . .	2·76	9·336	2·658	0·350	1·969	1·840	0·377	0·291
10. 75 per cent Ca clay and 25 per cent soil .	2·57	9·047	2·090	0·368	1·942	1·467	0·355	0·333
11. 50 per cent Ca clay and 50 per cent soil .	2·09	9·441	2·569	0·471	2·794	1·060	0·400	0·369
12. 25 per cent Ca clay and 75 per cent soil .	1·84	10·649	3·007	0·484	2·995	0·984	0·416	0·377
D—Magnesium group								
13. 100 per cent magnesium clay . . .	1·57	13·420	4·357	0·840	4·593	0·464	1·095	0·827
14. 75 per cent Mg clay and 25 per cent soil .	1·84	12·365	4·116	0·753	4·638	0·524	0·984	0·808
15. 50 per cent Mg clay and 50 per cent soil .	1·63	12·408	4·494	0·619	4·162	0·653	0·798	0·789
16. 25 per cent Mg clay and 75 per cent soil .	1·56	12·483	4·656	0·536	3·736	0·710	0·742	0·779
17. 100 per cent original soil . . .	1·56	11·631	4·100	0·203	2·616	0·771	0·554	0·397

Availability of exchangeable bases to plant

From a study of the analytical data (Table XI) much information is gained regarding the influence of different cations in the exchange complex on the absorption of individual bases. The general trend of absorption is represented graphically in Fig. 2. The following salient points may, however, be noted :

1. The plants removed the largest amount only of those bases which predominate in the soil's exchange complex. This is in accordance with the findings of other workers [Singh and Nijhawan 1936].

2. The variation in sodium and potassium contents of crops removed from sodium and potassium soils respectively due to a change in the degree of saturation is greater than the variation in calcium and magnesium contents of the crop removed from the respective soils.

3. The dominant base in the exchange complex greatly affects the absorption of other bases by the plant. In sodium soils, an increase in the amounts

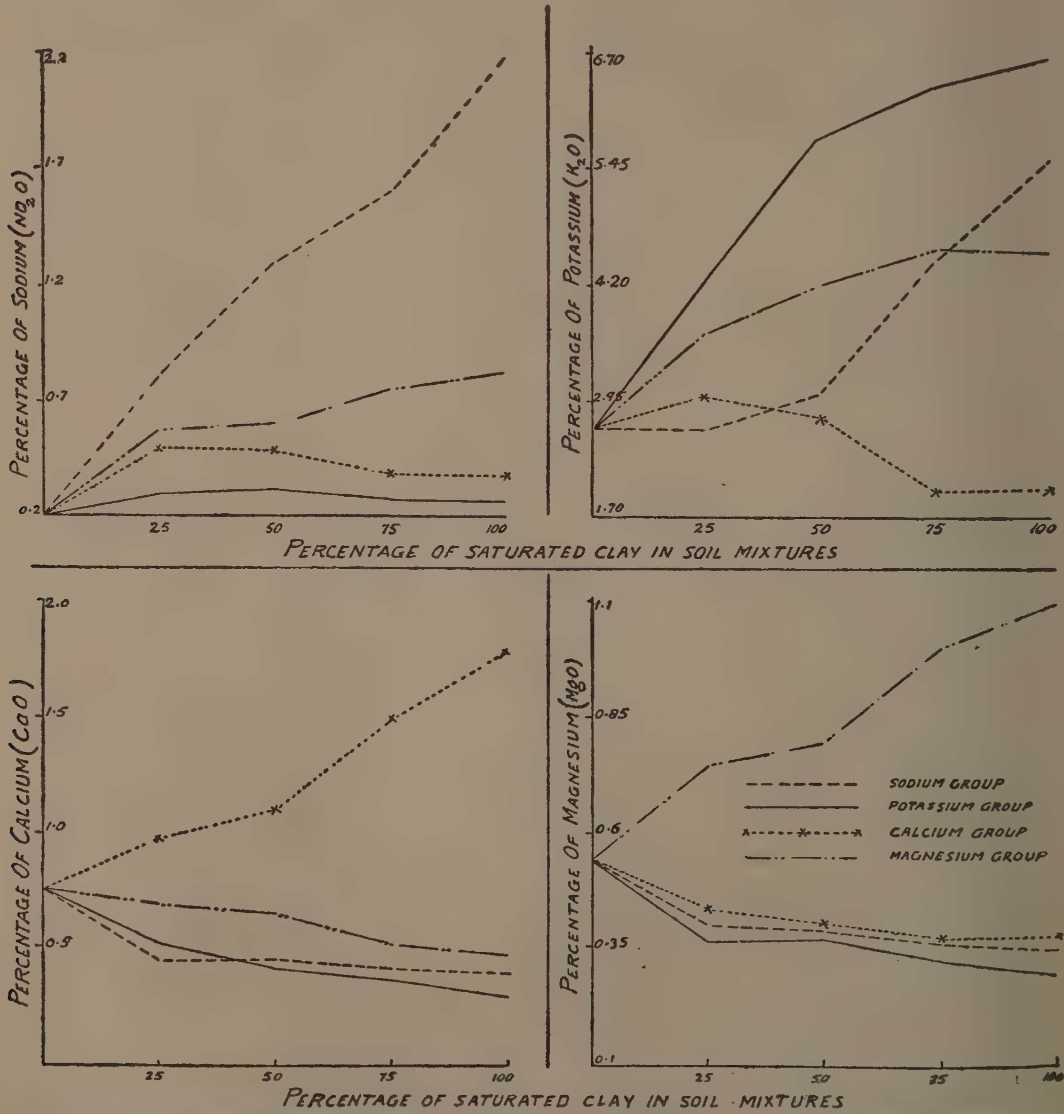

FIG. 2. Influence of exchangeable bases on the composition of wheat crop (sodium, potassium, calcium and magnesium)

of sodium increased the absorption of potassium but decreased the absorption of divalent bases, while in the case of potassium soils an increase of potassium ions not only suppressed the absorption of divalent bases but of sodium as well. Thus, it will be observed that whereas sodium ions promote the uptake of potassium, reverse is the case with potassium ions. Calcium soils showed a behaviour similar to those of potassium soils, with the only difference that the absorption of magnesium is not suppressed to the same extent as in the case of soils containing monovalent bases. Magnesium soils, on the other hand, behaved in an entirely different manner from other bases, as they increased the absorption of monovalent bases but suppressed the absorption of calcium.

4. The order of absorption of different bases from soils containing different cations is variable, e.g. calcium is absorbed in the largest proportion from calcium soils, and in the diminishing order from magnesium, potassium and sodium soils. These relationships are summarized below :—

Mineral constituent	Order of absorption from soils treated with different bases
CaO	Ca>Mg>K>Na
MgO	Mg>Ca>Na>K
Na_2O	Na>Mg>Ca>K
K_2O	K>Na>Mg>Ca

Availability of phosphorus

From the data presented in Table XI and Fig. 3 it will be observed that the nature of cations not only affects the absorption of different bases, but also produces a profound effect on the uptake of phosphoric acid.

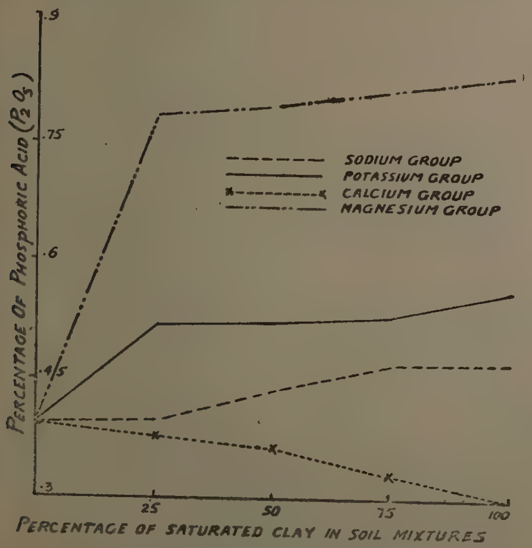

Fig. 3. Effect of exchangeable bases on the availability of phosphoric acid to wheat crop

The crop grown on magnesium soils contained the highest percentage of phosphoric acid, which increased from 0·78 to 0·83 per cent with an increase in the exchangeable magnesium. The next highest amount of phosphoric acid was removed from potassium soils, where the percentage varied from 0·52 to 0·56. The percentage of phosphoric acid removed from sodium soils was much less than that from magnesium or potassium soils, and was least in the case of calcium soils, the percentage varying from 0·29 to 0·38. In all cases with an increase in the exchangeable bases the amount of phosphoric acid removed by the crop increased, except in the case of calcium soils where an increase in the exchangeable calcium suppressed the absorption of phosphoric acid. Thus the order of absorption of phosphoric acid was Mg>K>Na>Ca.

General discussion

The crop yields from all the sodium and potassium treated pots are much below the control. At 75 per cent and 100 per cent levels they are found to be equally injurious to plant growth, but at lower levels (25 per cent and 50 per cent) potassium is not quite as harmful as sodium. Magnesium soils have given slightly better results than the control, but the calcium soils produce a marked beneficial effect on plant growth. The better growth of plants, as depicted by height measurements, the average number of tillers per pot, and the yield data, is due to an increased absorption of calcium by the plants, which is directly proportional to the amount of exchangeable calcium present in the soil. The plants grown on sodium, potassium, and magnesium soils remove decreasing amounts of calcium with increasing amounts of their respective cations, while reverse is the case when grown on calcium soils, i.e. the absorption of calcium is increased with an increase in the amount of exchangeable calcium. Thus, there exists a relationship between the exchangeable calcium of the soil and the plant growth, which increases significantly with an increase in the amount of exchangeable calcium [Gedroiz 1931].

The nature of cations absorbed by the soil also greatly affects the solubility of phosphorus. It is observed that the percentage of phosphoric acid increases in wheat crop to a maximum when grown in soils saturated with magnesium [Perkin, *et al.* 1932], while it is reduced to a minimum in soils saturated with calcium. The available analyses of the soils saturated with these cations also indicate the same fact, i.e. the amount of available phosphoric acid in calcium-saturated soils decreases, while that of magnesium soils increases. The increase of phosphoric acid in the crop grown on magnesium soils is probably due to the fact, as pointed out by Miller [1938], that magnesium acts

as a carrier of phosphorus. The salts of magnesium undergo dissociation very easily, and thus readily give up the anions which they carry.

The decrease in the percentage of phosphoric acid removed by the crop from calcium-saturated soil shows that phosphates are held up in the soil in a less readily available form. The fixation of phosphates may be due to the formation of calcium phosphate complexes, and the availability of phosphoric acid in calcium soils is one of the principal problems in the application of fertilizers to crops. Again, if they are held up in the soil in such a form as is unable to penetrate to the lower layers, it may be necessary to apply phosphatic manures in a form that is able to reach the root zone.

Similarly, the addition of calcium clay depresses the supplies of potash to the crop. It is surmised that this depressing effect may not be due to a decreased solubility induced by the addition of calcium clay, but due to a diminished supply of available soil potash caused by the replacement of potassium by calcium. This view is strengthened by the fact that the available potash content in calcium-saturated soil is less than that in the control.

The results obtained in the foregoing pages indicate that the exchangeable cations in the soil affect the availability of plant nutrients. Calcium bases increase the uptake of calcium by the plant, whereas sodium, potassium, and magnesium bases seem to depress its absorption. The maximum effect in this respect is produced at the point of saturation. Thus, the nature and amount of cations exercise an important influence on the fertility of the soil.

Summary and conclusions

The data presented in this investigation point out the important rôle played by the exchangeable bases on the growth and the composition of wheat crop. The study was carried out on an average soil from the Lyallpur Agricultural Farm.

The investigation involved the preparation of soils containing varying amounts of exchangeable bases. Data have been presented on the germination, growth, and yield of wheat crop grown on different soils. The amount of plant food material removed from these soils was determined by ash analyses of the crop.

The main conclusions arrived at as a result of these experiments may be summarized as follows :

1. The displacement of bases in the soil by any single base does not take place to the entire exclusion of the other. The degree of saturation varies with the nature of the cations and the order of displacement is Ca>Na>Mg>K.

2. (*a*) The nature of cations also affects the soil reaction considerably, sodium soils exhibiting the highest *p*H value, and the calcium soils the lowest. The order of soil reaction is Na>K>Mg>Ca.

(*b*) A change in the amount of exchangeable sodium brings about the greatest variation in the *p*H values of the soil, but a corresponding change in the calcium content produces only a small variation.

3. Germination is delayed in soils treated with monovalent bases.

4. Growth and yield of wheat crop is invariably better in soils treated with divalent bases than in those treated with monovalent bases. Calcium-saturated soils have given the best results, while sodium-saturated soils have proved to be most harmful. There is a progressive increase in yield as the amount of exchangeable calcium increases.

5. The percentage of mineral matter removed is the largest from potassium soils, and the least from calcium soils.

6. (*a*) Plants are observed to enjoy luxury consumption of the base which is in excess in the soil's exchange complex.

(*b*) The dominant base also greatly affects the absorption of other bases by the plant. Generally speaking, it suppresses the absorption of other bases, but sodium soils increase the absorption of potassium, and magnesium soils of both the monovalent bases.

(*c*) The order of absorption of different bases from soils containing different cations is variable.

7. The crop removes the maximum amount of phosphoric acid from magnesium soils, and the least from calcium soils. Increasing amounts of exchangeable calcium suppress the absorption of phosphorus by the plant.

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STUDIES ON THE DISTRIBUTION OF DIFFERENT FORMS OF PHOSPHORUS IN INDIAN SOILS

II. VERTICAL DISTRIBUTION

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IN a previous paper the authors [Ghani and Aleem, 1943] have studied the distribution of phosphorus in the surface samples of a number of Indian soils collected from different localities and have discussed its importance with regard to the practical aspect of phosphate availability. In view of the interesting results obtained it was thought that a study of the vertical distribution of the phosphorus fractions in profile samples might give useful information. In the few attempts that have been made in the past attention has been confined mainly to the variation of the total phosphorus and dilute acid-soluble phosphorus with depth. There has been some speculation also as to the nature of phosphorus compounds that occur at different horizons of the soil profile [Heck, 1934; Pearson and others, 1940]. From the latter point of view, a fractionation study in the proposed manner would be of great value. With this object the profile samples from eight soils collected from different parts of India have been fractionated according to the procedure described by one of the authors [Ghani, 1942]. A brief description of the soils is given below.

DESCRIPTION OF SOILS

No. 1. Dacca, Bengal

(*a*) 0—6 in. . Grey coloured loamy soil slightly dark due to organic matter. *p*H 5·2.

(*b*) 6 in.—2 ft. 3 in. Yellowish grey heavy loam, sparsely mottled with iron. *p*H 5·3.

(*c*) 2 ft. 3 in.—4 ft. Yellowish grey clay soil with numerous iron mottlings. *p*H 5·3.

No. 2. Bidar, Hyderabad (Deccan)

(*a*) 0—1 ft. . Brownish sandy soil mixed with 'murrams' of purplish gravel and of a few whitish nodular material. *p*H 6·2.

(*b*) 3—4 ft. . Decomposed trap mixed with a lot of whitish, yellowish material and a little soil. *p*H 6·4.

No. 3. Himayetsagar, Hyderabad (Deccan)

(*a*) 0—3 in. . Red sandy loam soil, parent material—granite. *p*H 6·4.

(*b*) 3 in.—1 ft. 6 in. Red sandy loam mixed with gravels. *p*H 6·4.

(*c*) 1 ft. 6 in.—4 ft. Friable decomposed rock containing whitish material said to be due to decomposition of pigmatite. *p*H 7·3.

No. 4. Telankheri, Nagpur (C. P.)

(*a*) 0—2 in. . Red sandy loam mixed with boulders of partially decomposed basalt. *p*H 6·3.

(*b*) 2 in.—2 ft. 6 in. Red sandy loam mixed with larger boulders of partially decomposed basalt. *p*H 6·4.

(*c*) 13—16 ft. . Grey decomposed material. *p*H 6·7.

No. 5. Chandkheri, Raipur (C. P.)

(*a*) 0—4 in. . Light red loam soil mixed with iron concretions. *p*H 5·8.

(*b*) 4 in.—1 ft. 5 in. Red soil mixed with large amounts of iron concretions. *p*H 5·8.

No. 6. Buksa forest division, Rydak Forest (Assam)

(*a*) 0—9 in. . Light brown silt loam. *p*H 4·5.

(*b*) 9 in.—1 ft. 6 in. Slightly reddish loamy soil. *p*H 4·5.

(*c*) 1 ft. 6 in.—2 ft. 3 in. Do. *p*H 4·4.

No. 7. Kurseong forest division, Sukna Reserve Forest (Bengal)

(*a*) 0—9 in. . Grey coloured silty loamy soil. *p*H 4·5.

(*b*) 9 in.—1 ft. 6 in. Slightly redish. *p*H 4·3.

(*c*) 1 ft. 6 in.—2 ft. 3 in. Do. *p*H 4·1.

No. 8. Tenaserim (Burma)

(*a*) 0—6 in. . Dark loamy soil. *p*H 4·2.

(*b*) 6—12 in. Do. *p*H 4·2.

DISCUSSION OF RESULTS

The results of fractionation expressed both as mg. P_2O_5 per 100 gm. of soil and as per cent of the total P_2O_5 are given in Table I.

Total phosphorus

It will be seen from Table I that the total soil phosphorus is lower in the second depth (subsurface) of all the eight soils. In soil No. 4 there is a very slight increase though the rate of fall is different in different profiles. But the third depth

or subsoil samples in four out of five soils show an increase, in some cases considerable, over the subsurface samples, which goes to show that the total soil phosphorus is at a minimum at the subsurface layers. The evidences given by the previous workers are rather conflicting in this respect.

TABLE I

Vertical distribution of phosphorus fractions

Profiles	Acetic acid-sol.		Alk.-sol. inorg.		Organic		Sulphuric acid-sol.		Insoluble		Total
	A*	B†	A	B	A	B	A	B	A	B	A
1. Dacca, Bengal—											
0—6 in.	1·6	2	16·6	17	63·4	66	8·6	9	5·4	6	95·6
6 in.—2 ft. 3 in.	*Nil*	...	10·7	12	61·8	69	5·2	6	11·5	13	89·2
2 ft. 3 in.—4 ft.	Trace	...	10·0	15	41·2	62	6·0	10	8·8	13	66·0
2. Bidar, Hyderabad—											
0—1 ft.	700·0	50	229·3	16	26·7	2	63·8	5	382·0	27	1400·0
3—4 ft.	26·0	17	36·3	24	20·3	14	16·0	11	51·4	34	150·0
3. Himayetsagar, Hyderabad—											
0—3 in.	Trace	...	Trace	...	26·6	24	9·2	8	75·3	68	111·1
3 in.—1 ft. 6 in.	*Nil*	...	12·0	23	22·0	42	Trace	...	18·7	35	52·7
1 ft. 6 in.—4 ft.	43·0	28	21·3	14	10·7	7	28·0	18	51·0	33	154·0
4. Telankheri, Nagpur—											
0—2 in.	1·6	1	16·0	8	33·0	18	4·0	2	135·4	71	190·0
2 in.—2 ft. 6 in.	Trace	...	16·0	28	21·0	38	4·0	7	15·3	27	56·6
13—16 ft.	156·0	63	125	5	46·5	19	12·0	5	18·6	8	245·6
5. Chandkheri (C. P.)—											
0—4 in.	Trace	...	21·3	20	19·7	18	12·5	12	53·3	50	106·8
4 in.—1 ft. 5 in.	*Nil*	...	12·5	11	26·7	24	5·0	4	65·8	60	110·0
6. Buksa forest—											
0—9 in.	3·3	2	31·0	17	108·3	60	18·0	10	20·5	11	181·1
9 in.—1 ft. 6 in.	Trace	...	22·9	17	62·4	48	23·2	18	22·4	17	130·9
1 ft. 6 in.—2 ft. 3 in.	Trace	...	22·5	15	102·8	70	19·2	12	4·6	3	149·1
7. Kurseong forest—											
0—9 in.	Trace	...	28·8	14	88·5	42	19·6	9	73·8	35	210·7
9 in.—1 ft. 6 in.	Trace	...	26·6	17	96·0	62	22·4	15	9·6	6	154·6
1 ft. 6 in.—2 ft. 3 in.	Trace	...	26·1	17	80·5	51	18·0	12	31·0	20	155·6
8. Tenaserim—											
0—6 in.	6·1	3	26·0	13	59·3	31	14·0	7	88·6	46	194·0
6—12 in.	2·3	2	33·3	25	39·3	29	5·0	4	54·5	40	134·4

* A means mg. P_2O_5 per 100 gm. of soil † B means P_2O_5 in per cent of the total P_2O_5

Wheeting's [1924] results with five Michigan soils showed wide differences in the relative amounts of phosphorus found at four depths. In two of the soils highest percentage was found in the A-horizon, in two other in the B-horizon and in one soil in the C-horizon. Stephenson and Chapman [1931] found no correlation between the phosphorus content of various layers in eleven California soils. Walker and Brown [1936] analysed samples taken at 0-6⅔ in. and 20-40 in. and found that larger amount of phosphorus was present in the surface layers than in the lower zone.

Odynsky [1936] found that in four of the five Alberta soils, total phosphorus was at its minimum in the intermediate layers whereas in one soil it regularly decreased with depth. Pearson *et al.* [1940] in a study of 12 Iowa soil profiles found that in all cases the total phosphorus decreased with depth to a minimum between the lower A and the upper C horizons. Below this zone in 11 of the 12 soils, the amounts increased rapidly with depth to the bottom of the profile.

The results obtained here are similar to those obtained by Odynsky and Pearson. Pearson

suggested that the difference in the location of zones of maximum root development within the profiles may be responsible for variations in phosphorus distribution. That this is the case will appear from the vertical variation of the total phosphorus in the profiles of the two forest soils Buksa and Kurseong. In these two profiles, the differences in phosphorus content of the second and third depths are extremely small. Obviously this is due to an enlargement and downward shift of the zones of root development and phosphorus absorption, necessitated by the growth of forest trees. In the soils under ordinary crops and grass, the zone of maximum absorption is naturally located further up, as a result of which much phosphorus will be drawn from the subsurface layers impoverishing it by the process.

Acetic acid-soluble phosphorus

The acetic acid-soluble phosphorus is present only in traces in almost all the soils at all depths. Undoubtedly this is due to the acid nature of the soils. Only in the Bidar soil whose pH is above 6 and in the subsoil sample of Hemayetsagar whose pH is 7·3 the fraction occurs in a high proportion. Unfortunately these trace values of acetic acid-soluble phosphorus have made it impossible to detect the nature of change of the fraction down the profile. However, in many of the soils the surface samples contain some available phosphorus, though very small, while at the second depth it is practically absent. Soil No. 2 which is conspicuously rich in phosphorus contains 50 per cent of it in this form in the surface sample and the amount decreases to 17 per cent in a lower layer. This may probably indicate a downward decrease of the acetic acid-soluble fraction. In two of the soils (Nos. 3 and 4) 28 and 63 per cent respectively occur in the lowest layer though there is practically nothing in the upper layers. Though these results do not point to any definite conclusion yet they may add to the meagre stock of information that we possess on the subject.

Alway, McDole and Rost [1917] reported that citric acid-soluble phosphorus increased rapidly to a depth of 6 ft. and then remained constant in several soils developed from loess. Stephenson and Chapman [1931] found an increase in soluble phosphorus with depth in four of the eleven California soils. Lohsey and Runke [1933] reported an increase of soluble phosphorus with depth below the A_2-horizons of virgin podsolic and brown forest soils in Ontario. Odynsky [1936] found that phosphorus dissolved by $0{\cdot}002N$ sulphuric acid increased with depth throughout the profiles of three dark coloured unleached Alberta soils. Romine and Metzer [1939] using the same reagent found that soluble phosphorus was lower in the B than in the A horizons of six out of eight prairi soils. Pearson *et al.* [1940] showed that in nine out of twelve soils, dilute acid-soluble phosphorus increased in the lower A or upper B horizons. In seven of the soils the lower layers contained more than 25 per cent soluble phosphorus and in one soil 55 per cent as compared with 0·94 to 3·63 per cent found in the surface layers.

Alkali-soluble inorganic phosphorus

Table I shows that this fraction (iron and aluminium phosphates) decreases downwards in six out of the eight profiles. In two of the soils (Nos. 3 and 8) it shows a tendency to increase with depth. When the fractions are considered as per cent of the total phosphorus it is found that in six of the soils per cent iron and aluminium phosphates is higher in the second depth and then again it is lower in the third depth, showing that a maximum is attained in the intermediate layers. These are the same soils which showed a minimum of total phosphorus in the intermediate layers. It has already been pointed out that the intermediate layers may in all probability represent the zone of maximum absorption, at least in all arable and grassland soils. Accumulation of iron and aluminium phosphates keeping in harmony with the depletion of total phosphates in this layer may only mean that this form of phosphorus has not been removed by the plants to any appreciable extent. This gives an additional support to the prevailing view that iron and aluminium phosphates are comparatively unavailable to plants. A noticeable difference can again be observed in the behaviour of the two forest soils. In these cases also the fraction is at its maximum in the middle layer but the difference between the two lower layers is extremely small. This shows that accumulation of iron phosphates has progressed at the same rate in the two-layers, both being located within the zone of root development of the forest vegetation.

Sulphuric acid-soluble phosphorus

The phosphorus soluble in $2N$ sulphuric acid (apatites) is comparatively small and constitutes the single lowest fraction in the samples studied. The nature of changes with depth is practically the same as was observed with the alkali-soluble inorganic fraction. In the majority of the soils it reaches a maximum in the intermediate layers. As regards its availability, the same consideration will show that it is of little use to plants.

Insoluble phosphorus

The insoluble fraction varies with depth in a rather haphazard fashion. In three of the soils (Nos. 3, 4 and 8) per cent insoluble phosphorus regularly decreases whereas in the three others (Nos. 1, 2 and 5) it shows a regular increase. In one soil (No. 7) the intermediate layer contains the

lowest proportion, and another soil (No. 6) shows a maximum at the middle layer. Taking the absolute values of the fraction (mg. P_2O_5 per 100 gm. of soil) it is found that three of the soils show a minimum value and two a maximum value at the intermediate depth.

Organic phosphorus

In six of the soils the amount of organic phosphorus (per 100 gm. of soil) shows a decrease in the subsurface; in two of them there is again a rise in the third depth. In one there is a slight tendency to increase downwards while in another a maximum amount is present in the middle layer. Again, when the fraction is expressed as per cent of the total soil phosphorus in most of the soils the highest percentage is present in the second depth. This shows as before an accumulation of organic phosphorus as a comparatively unavailable fraction in the intermediate layers in the profile. Auten [1922] found that in two of the three profiles he studied, organic phosphorus expressed as pounds per acre regularly increased up to the subsoil (third depth) while in one a minimum was reached at the subsurface layer. He further found that the ratio of total phosphorus to organic phosphorus was maximum in the middle layer in two of the soils and regularly increased in one.

For obvious reasons, the accumulation of organic phosphorus depends on many other soil factors besides the distance of the layer from the surface, as it is bound up with the occurrence of organic matter and its rate of decomposition.

It was, therefore, thought desirable to study the organic phosphorus in its relation to organic carbon and nitrogen and to examine the nature of variation of these constituents with their distance from the surface. Very little information is available at present on such relationships. Reference can only be made to the work of Auten [1922] who, in his study of the surface and subsurface samples of four Iowa soils, found the ratio of organic phosphorus to organic carbon to vary from 1/93 to 1/329 and the ratio of organic phosphorus to nitrogen to vary from 1/8 to 1/24.

C/N, C/P and N/P ratios

The carbon to nitrogen, carbon to organic phosphorus, and nitrogen to organic phosphorus ratios of the profile samples are presented in Table II.

It will be seen from Table II that organic carbon and nitrogen regularly decrease with depth in all the soils excepting No. 5. The organic phosphorus figures also indicate a similar behaviour. In soil No. 5 which shows a rise in the carbon content with depth, both nitrogen and organic phosphorus also exhibit a similar change. The downward decrease of the three constituents is not however in the same proportion, as will be evident from a comparison of the three ratios.

TABLE II

C/N, C/P and N/P ratios at different depths

Soil	Org. C per cent	Nitrogen per cent	Org. P per cent	C/N	C/P	N/P
1. Dacca—						
0—6 in.	1·260	·111	·028	11·3	45·0	3·9
6 in.—2 ft. 3 in.	0·567	·067	·027	8·3	21·0	2·5
2 ft. 3 in.—4 ft.	0·385	·048	·018	8·0	21·4	2·6
2. Bidar—						
0—1 ft.	0·772	·040	·012	19·3	64·3	3·3
3—4 ft.	0·349	·023	·009	15·1	38·8	2·6
3. Hemayetsagar—						
0—3 in.	0·607	·057	·012	10·6	50·6	4·7
3 in.—1 ft. 6 in.	0·515	·055	·010	9·4	51·5	5·5
1 ft. 6 in.—4 ft.	0·055	·008	·005	6·5	11·0	1·6
4. Telankheri—						
0—2 in.	1·471	·106	·014	13·9	105·0	7·5
2 in.—2 ft. 6 in.	1·122	·089	·009	12·6	124·7	9·9
5. Chandkheri—						
0—4 in.	0·668	·047	·009	14·2	74·2	5·2
4 in.—1 ft. 5 in.	0·956	·062	·010	15·4	95·6	6·2
6. Buksa—						
0—9 in.	3·192	·213	·047	15·0	67·9	4·5
9 in.—1 ft. 6 in.	1·841	·116	·027	16·1	68·2	4·3
1 ft. 6 in.—2 ft. 3 in.	0·851	·085	·045	10·0	18·9	1·9
7. Kurseong—						
0—9 in.	2·300	·194	·037	11·9	62·2	5·2
9 in.—1 ft. 6 in.	1·590	·145	0·42	11·0	37·8	3·4
1 ft. 6 in.—2 ft. 3 in.	1·050	·106	0·35	9·8	30·0	3·0

The C/N ratio varies from 10·6 to 19·3 in the surface samples, the average value being 13·7. In the subsurface samples it varies from 8·3 to 16·1, the average value being 12·1. In the subsoil samples the ratio varies from 6·5 to 15·1 with an average at 9·9. The average ratio varies from 13·7 to 9·9 down the profile.

The C/P ratio varies from 45·0 to 105·0 in the surface, the average value being 67·0. In the subsurface it varies from 21·0 to 124·7 with an average at 66·5. In the subsoil samples, the ratio varies from 11·0 to 38·8, the average value being 24·0. The average ratio varies from 67·0 to 24·0 down the profile.

The N/P ratio varies from 3·3 to 7·5 in the surface with an average at 4·9. In the subsurface the ratio varies from 2·5 to 9·9, the average value being 5·3. At the subsoil layer it varies from 1·6 to 3·0 with an average of 2·3. The average ratio varies from 4·9 to 2·3 with depth with a maximum of 5·3 at the subsurface. The average variation of the three ratios at different depths are shown in Table III.

TABLE III

Average variation of C/N, C/P and N/P ratios with depth

Soil	C/N			C/P			N/P		
	Min.	Max.	Average	Min.	Max.	Average	Min.	Max.	Average
Surface (7 samples)	10·6	19·3	13·7	45·0	105·0	67·0	3·3	7·5	4·9
Subsurface (6 samples)	8·3	16·1	12·1	21·0	124·7	66·5	2·5	9·9	5·3
Subsoil (5 samples)	6·5	15·1	9·9	11·0	38·8	24·0	1·6	3·0	2·3

The above results will further show that, as compared with organic carbon, both nitrogen and organic phosphorus breakdown at a lower rate in the lower horizons of the profile. This is revealed in a regular decrease of the C/N and C/P ratios down the profile. Again as compared with nitrogen, the rate of breakdown of organic phosphorus lessens with depth as is shown by the narrowing down of the N/P ratio. In Telankheri and Chandkheri soils the C/P and N/P ratios increase with depth. In the latter soil the higher carbon and nitrogen content at subsurface is mainly responsible for this increase. In so far as these findings will justify generalization it may be said that as the depth of the layer increases the rate of disappearance of these elements from the soil organic matter is of the order C>N>P or in other words, at lower depths the phosphatic organic matter is the most resistant of all.

It may also be readily observed from the above data that the correlation between organic carbon and organic phosphorus, and between nitrogen and organic phosphorus, would be fairly significant.

SUMMARY

A study has been made of the vertical distribution of various phosphorus fractions in a number of profiles.

The total soil phosphorus is at a minimum in the intermediate layers of the profiles, showing that phosphate absorption by plants is maximum in those layers.

The acetic acid-soluble phosphorus decreases with depth ; in some cases it is at its minimum at the middle layer.

Iron and aluminium phosphates expressed as percentage of the total phosphorus are usually at their maximum at the intermediate layers—the zones of maximum root development and phosphorus absorption showing that they are unavailable to plants. The apatite phosphate varies more or less in the same way.

Organic phosphorus, organic carbon and nitrogen decrease with depth in most of the soils. But expressed as per cent of the total phosphorus, organic phosphorus is present in the highest percentage in the second depth. On an average, C/N and C/P ratios decrease with depth whereas the N/P ratio shows a maximum in the subsurface.

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A PRELIMINARY STUDY OF RESPIRATION IN RELATION TO NITROGEN METABOLISM OF POTATO TUBERS

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(With two text-figures)

It has been known for a considerable time that the exposure of surface to air after injury is accompanied by enhanced oxygen absorption and carbon dioxide production. Associated with the increased respiration rate some observation on regeneration have been made by Steward, Wright and Berry [1932], with cut discs of potato. They noted the production of prominent cytoplasmic strands with renewed protoplasmic streaming, the increase in the size of the nucleus and occasional cell division in the surface cells exposed to air. They postulated that these cytoplasmic changes culminating in meristematic activity would involve transformation in the nitrogenous substances within the cells.

The chemical changes in response to these activities of regeneration have been observed to a limited degree. Thus Gruss [1907] noticed an accumulation of sugar and an increase in the oxidizing enzymes and in the diastatic activity of the cells around the wounded potato. It was observed by Hopkins [1927] that the sugar content of the wounded potato increased with the disappearance of starch from the surface cells. Fredrich [1908] noted in the cells bordering the cut surfaces of potato an increase in total nitrogen and acidity and a decrease in total carbohydrate but an increase in reducing sugars. Besides these changes in carbohydrate content some observations have been made by Zaleski [1901], Heitlenger [1901], Kovchoff [1902], and Smirnoff [1903] on the nitrogenous substances of the wounded surface. The observations of all these investigators show that as a result of wounding an increase in protein nitrogen occurs, but no scheme has been suggested as to the way the soluble nitrogen passes into insoluble form. It was agreed by Smirnoff and Zaleski that in absence of air or in hydrogen these changes do not take place.

In the past a considerable amount of work has been done to advance the knowledge of protein synthesis in plants and in these investigations various plant organs have been employed to furnish evidence for the course of nitrogen metabolism. Amongst these the storage organs have not been adequately studied. Gruntuch [1929] noted that though the potato tubers have a low total nitrogen, yet they have also a very high soluble nitrogen. An observation on the transformation of such a high percentage of soluble nitrogen into protein nitrogen as a result of increased metabolic activities may add to our knowledge of protein synthesis in plants. The advantage of using cut discs of potato tuber exposed to air for such observations are as follows :

(1) In storage organs carbohydrate supply is adequate, which, besides being a source of energy for the synthetic cells, provides for the necessary carbon compounds of the protein molecule.

(2) The elimination of translocation prevents the loss or supply of any organic nitrogen to and from any other part of the organism so that the disappearance or production in excess of any particular nitrogenous compound may be directly accounted for the nitrogen metabolism of the organ.

(3) The observation is limited to a small bulk of uniform cells thus avoiding any complications due to complex tissue system.

(4) Storage tissue has been extensively used for salt absorption, the ability of which has been shown by Steward [1931] to be dependent on the physiologically active cells. In addition to the increased respiration rate the activities of the surface cells to regeneration have been mentioned before. The importance of salt absorption in these physiologically active cells concomittant with growth is obvious. From this it might be anticipated that the absorption of inorganic nitrogen by these cells may throw further light as to the way protein is normally synthesized in plants from inorganic nitrogen.

The experimental attack of the problem resolves itself into two main features to which simultaneous attention has been paid: firstly to the maintenance of proper conditions for allowing the cells to respire aerobically for a considerable time in an atmosphere free from carbon dioxide accumulation ; secondly the prevalence of ideal condition for salt absorption and water supply to the evaporating cells without interfering with aeration and carbon dioxide measurement during the course of the experiment.

Apparatus

The apparatus for the present investigation consists of two main parts (Figs. 1 and 2) ;

(1) The respiration chamber (R).

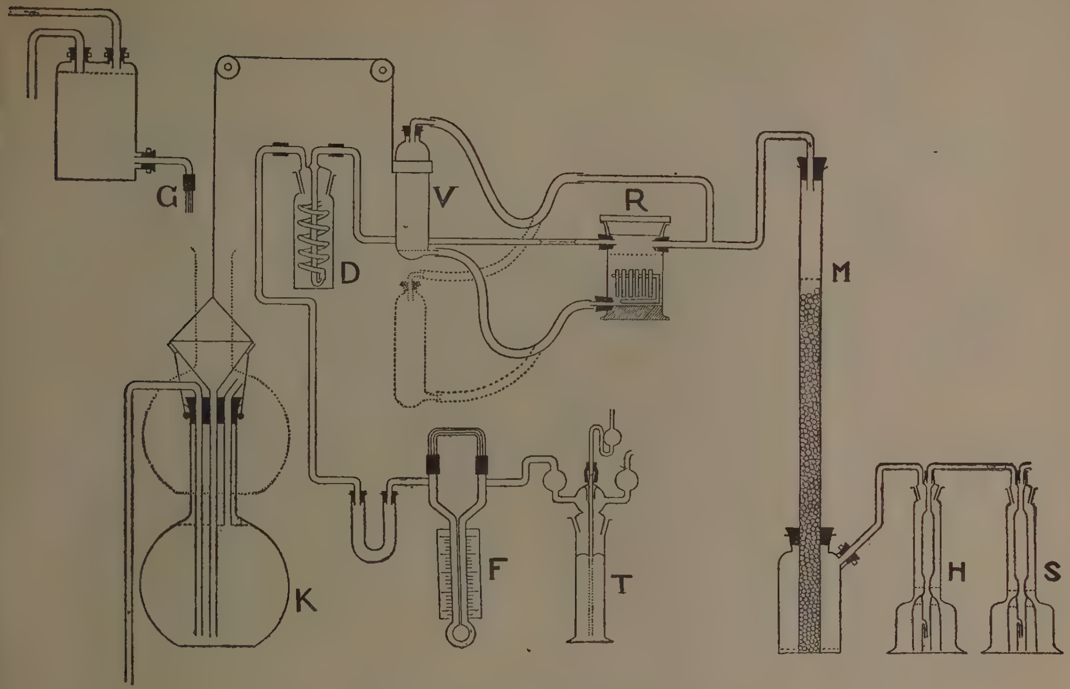

Fig. 1. Respiration apparatus

(2) The vessels (V), containing a liquid with accessory arrangements for the periodical flooding of the discs.

(1) *Respiration chamber* (R). This is a cylindrical jar with a ground glass stopper and provided with two holes just below the open end and one at the bottom. One of the upper holes serves as the inlet of carbon dioxide free air and the other at the opposite side allows the air stream containing respired carbon dioxide to be conveyed to the absorption bubblers (D). The hole at the bottom serves as an entry of culture solution to flood the discs. Six such jars are arranged in a parallel series in one plane. For aeration air free from any laboratory gas is drawn from outside the laboratory buildings by the suction of a filter pump. The air stream passes first through wash bottles (S, H) containing 20 per cent sulphuric acid and 40 per cent sodium hydroxide to remove atmospheric impurities and carbon dioxide. Finally the air stream before entering the respiration chamber is passed through a tower (M) packed with beads and containing 40 per cent sodium hydroxide to remove the last traces of carbon dioxide in the air. The carbon dioxide free air thus drawn enters the six respiration chambers through a combination of two (T) pieces ; one arm of the (T) piece is connected to the vessels in order to equalize the pressure between the vessels and the respiration chambers and the other arm joins three respiration chambers. Similarly with second (T) piece air is delivered into the other three chambers. Then the air stream containing the respired carbon dioxide is led into the spiral bubbler (D) containing sodium hydroxide for the absorption of carbon dioxide. Air from each of the spiral bubblers passes into a six-way glass tube, then through a capillary flow meter (F), protected by calcium chloride tube, and Mariotte bottle, T, is finally removed by the suction of the water pump.

(2) *The vessels* (V). The main principle of this part of the apparatus is to flood the discs periodically with a liquid at desired intervals, while in the intervening periods the discs are allowed to respire in air. The vessel for holding the liquid is made of pyrex glass and is provided with two openings, the one at the bottom for conveying the liquid is drawn to a tube which connects with the lower hole of the respiration chamber through elastic rubber tubing. Six such vessels corresponding to the six respiration chambers (Fig. 2) are clamped to a metal stand. Two pieces of string from the two ends of the metal stand passing over pulleys are fastened on the opposite sides of the neck of a flask (K) acting an intermittent siphon, in such a way that the movement of the pulleys allows the flask to rise and fall vertically. The flask is provided with a well-fitted stopper with three holes,

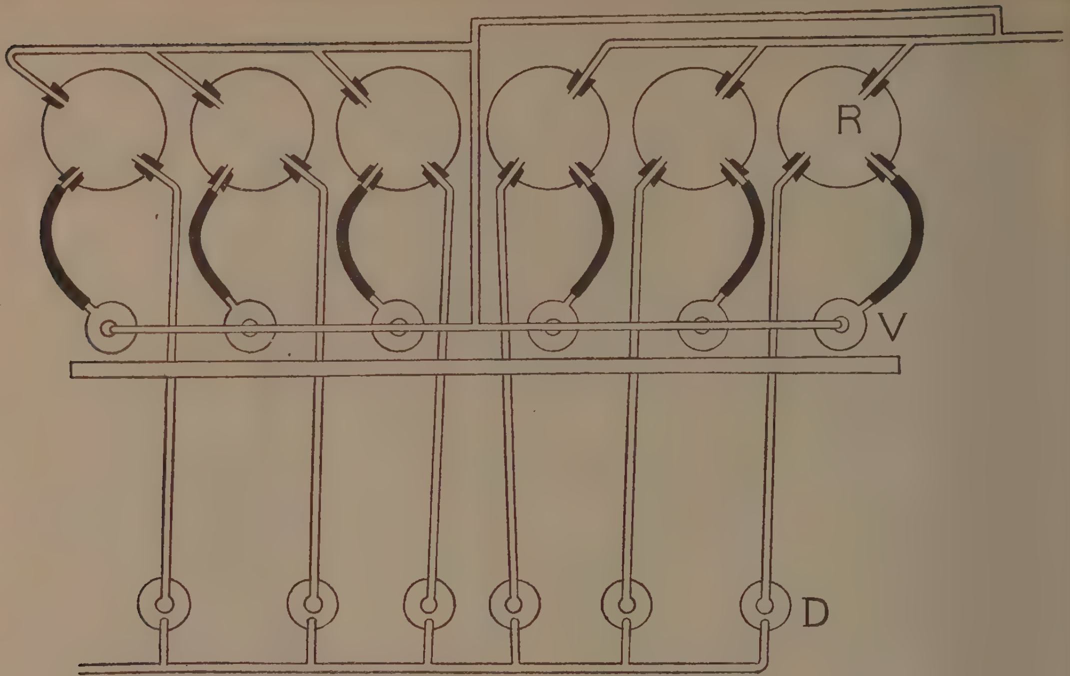

FIG. 2. Respiration apparatus showing the arrangement of respiration chambers (R), nutrient vessels (V), and alkali bubblers (D)

through one of the holes a siphon tube empties the water from the flask, the second is used for filling the flask through a funnel and the third hole allows inlet and outlet of air from the flask. The automatic movement of the flask is achieved by the working of the pulley system and the siphon tube. When the water level inside the flask rises to a certain height, the weight of the flask, becoming heavier than the combined weight of the metal stand and the vessels, lowers the former. By lowering of the flask the vessels are raised to a higher level and the discs are flooded with the liquid. The flask empties when the water level rises further to an adjustable height at which the siphon operates. The flask becoming lighter rises and the vessels fall by gravity and the discs are returned to air and the liquid flows back to the vessels. By the adjustment of the flow of water through a capillary (G) into the flask and the flow of the siphon tube, the interval for allowing the discs to respire in air and immersion in liquid alternately is maintained.

Experimental procedure

Cylinders of potato tuber (Var. King Edward VII) were cut symmetrically by means of a cork borer 3·2 cm. in diameter. These were then marked around with a string at distances of 3 mm. and cut into discs by a sharp scalpel. Discs having irregular thickness were discarded and those of approximately 3 mm. thickness were used. Six discs of 3 mm. thickness having a fresh weight of about 12 gm. could be conveniently arranged in each respiration chamber. For the complete analysis of all nitrogen fractions about 12 gm. of the fresh weight of the disc are necessary. Such discs, having a thickness of 3 mm. approximately, were used in all the experiments except in Experiment IV, where thicker discs were used. The discs of tissue were left in running tap water for 30 minutes to wash the starch grains from the cut cells. They were then superficially dried between filter paper, using a weighted photographic roller to ensure uniform drying and then weighed. All results are calculated in terms of this initial fresh weight. The control discs were also treated in a similar way and analysed immediately. Before the experiment is started, the apparatus is sterilized with formalin solution and thoroughly washed with distilled water. The discs are suspended vertically on a thin glass as shown in Fig. 1 and uniform spacing is kept between the adjacent discs. 75 c.c. of culture solution is used in each of the vessels for flooding the discs. The air stream is drawn for an hour to remove the last trace of carbon dioxide from the apparatus before beginning the experiment. A clean dry bubbler containing sodium hydroxide is then

connected to the respiration chamber to collect the respired carbon dioxide. Along with the change of the bubbler at the end of each period, fresh culture solution is used in the vessel. In order to remove any trace of carbon dioxide that may be held in the liquid, the liquid after each period is gently boiled while a stream of carbon dioxide free air is drawn through, and any carbon dioxide liberated is absorbed in alkali in the spiral bubblers. The liquid after each period of the experiment is preserved under sterile conditions to analyse whether any nitrogen has passed out of the disc into the liquid. The analysis of the liquid after evaporating down to a smaller bulk has shown that less than 1 per cent of nitrogen from the disc is lost in the culture solution in the vessels. The flow of air through the apparatus is maintained at five litres per hour, and care is taken to see that the air stream passes through the spiral bubblers at a uniform rate. The time during which the discs are allowed to respire in air was maintained at 9 minutes and 30 seconds. The discs were immersed in the solution for 1 minute and 30 seconds. With this arrangement the apparatus was very successfully run for a long period. At the end of the experiment the discs are found to be quite turgid and showed superficial browning similar to that noted by Steward [1931]. Immediately after the experiment the discs are dried superficially between the filter paper and their weights recorded. The discs are then divided into two portions: from one portion all soluble nitrogen fractions are analysed, and the other portion is dried at 100°C. for estimating total nitrogen. From the discs estimations of total nitrogen, total soluble nitrogen, protein nitrogen, total amino and amide nitrogen and residual nitrogen were made, according to the methods followed by Richards and Templeman [1936].

Estimation of carbon dioxide. The amount of carbon dioxide in the alkali in the bubbler is determined by noting the change in the conductivity of the alkali as described by Newton [1935]. The conductivity readings were taken by Dr R. Sankaran, to whom my thanks are due. The respiration rates are expressed as mg. of carbon dioxide per hour per gm. fresh weight of the disc.

Experimental results

Nitrogen metabolism

Preliminary experiments were performed to test the changes in the nitrogen metabolism occurring in the exposed disc under aerobic and anaerobic conditions at different temperatures. The production of carbon dioxide was not measured in these two experiments.

Experiment I. Six discs of 3 mm. thickness selected at random were used in each series. The control analysis was made immediately after sampling. The discs for aerobic respiration were kept for seven days in a Petri dish lined with moist filter paper; the loss of water from the discs was prevented by keeping the chamber moist. For anaerobic respiration the air from the intercellular spaces of the disc was exhausted by injecting water free from any dissolved gases. Then the discs were kept in a close chamber from which air was exhausted, the inside of the chamber was lined with moist filter paper. Both the series of the discs were kept at the laboratory temperature varying from 13° to 20°C. After seven days the discs were analysed for nitrogen fractions and the results are presented in Table I as percentage of fresh weight of the disc and in Table II as percentage of total nitrogen.

It is seen that the total nitrogen of potato tuber as percentage of fresh weight (Table I) is very low;

TABLE I

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 11·29 gm.	0·2590	0·2044	0·0546	0·0926	0·0429	0·0497	0·0621
Aerobic respiration fresh wt. 9·53 gm.	0·2590	0·1470	0·1120	0·0530	0·0194	0·0336	0·0604
Anaerobic respiration fresh wt. 10·13 gm.	0·2786	0·2100	0·0686	0·0966	0·0518	0·0448	0·0686

TABLE II

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	78 ·92	21 ·08	35 ·75	16 ·56	19 ·19	23 ·98
Aerobic respiration	56 ·76	43 ·24	20 ·46	7 ·49	12 ·97	23 ·32
Changes from the control	—22 ·16	+22 ·16	—15 ·29	—9 ·07	—6 ·22	—0 ·66
Anaerobic respiration	75 ·38	24 ·62	34 ·67	18 ·59	16 ·08	24 ·62
Changes from the control	—3 ·54	+3 ·54	—1 ·08	+2 ·03	—3 ·11	+0 ·64

of this about 79 per cent in the control is soluble nitrogen, the total amino, amide and residual nitrogen are high. Regarding the amide nitrogen the assumption is made that all amides in the plant exist in the form of asparagine. On this assumption the absolute values of amino-acids are estimated from the difference between the total amino and amide figures [Sircar and Sen 1941]. On this basis it is observed that the tuber contains more amides than amino-acids as the control analysis shows here.

After seven days aerobic and anaerobic respiration the discs were found to be quite turgid. In the case of aerobic respiration superficial browning of the discs as noted by Steward [1931] was seen, but under anaerobic condition no such change in colour is observed. As a result of aerobic respiration for seven days at the temperature varying between 13° to 20°C. a considerable amount of protein is synthesized (Tables I and II).

It is evident that the increase in protein nitrogen is accompanied by a decrease in amino-acid and amide nitrogen, while the residual nitrogen remains at about the same level as in the initial analysis. It is noted that under aerobic condition there is more decrease from the control value in amino-acids than in amides. Under anaerobic condition the synthesis of protein is small. Together with the small increase in protein nitrogen the amino-acid nitrogen has also increased while the amide nitrogen alone has disappeared to the extent to which the protein is formed.

Experiment II. The second experiment was performed in a way similar to Experiment I, the temperature in this case was maintained constant at 25°C. The results of the nitrogen analysis are entered in Tables III and IV.

TABLE III

Nitrogen as percentage of fresh weight

—	Total N	Total cryst N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 11 ·26 gm.	0 ·2422	0 ·1176	0 ·1246	0 ·0419	0 ·0055	0 ·0364	0 ·0393
Aerobic respiration fresh wt. 12 ·03 gm.	0 ·2422	0 ·1414	0 ·1008	0 ·0501	0 ·0165	0 ·0336	0 ·0577
Anaerobic respiration fresh wt. 11 ·99 gm.	0 ·2184	0 ·1092	0 ·1092	0 ·0644	0 ·0358	0 ·0266	0 ·0182

TABLE IV

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	48·55	51·45	17·30	2·27	15·03	16·22
Aerobic respiration	58·38	41·62	20·69	6·82	23·87	23·82
Changes from the control	+9·83	—9·83	+3·39	+4·55	—1·16	+7·60
Anaerobic respiration	50·00	50·00	29·49	17·31	12·68	8·33
Changes from the control	+1·45	—1·45	+12·19	+15·04	—2·35	—7·89

The sample in this experiment was collected from a different batch of potatoes, but the total nitrogen is about the same as in Experiment I. Of this more than 50 per cent is in the form of protein nitrogen as seen in the control analysis. It is interesting to note that corresponding to high protein nitrogen there is only 2 per cent amino-acid nitrogen whereas the amide nitrogen is maintained high. The nitrogen metabolism has resulted in the breakdown of protein after seven days of aerobic respiration at a temperature maintained constant at 25°C. The degradation of protein has resulted in the increase in amino-acids and residual nitrogen, the increase is considerably greater in amino-acids than in any other fractions under aerobic condition. The amide nitrogen is reduced to a small extent.

At the end of seven days anaerobic respiration at this temperature, the discs became soft and some of the nitrogenous substances have diffused out of the cells, consequently the total nitrogen estimated as percentage of fresh weight is low. Of the total nitrogen that was estimated in these discs equal amounts of protein and soluble nitrogen are noticed (Tables III and IV). The amino-acid has increased considerably, the amide and the residual nitrogen have decreased.

Carbon dioxide production

Experiment III. For the third experiment the apparatus as described before has been used. The discs of average 3 mm. thickness are allowed to respire in the respiration chambers and are periodically flooded with water. The experiment is started with two series, one of short period and the other of longer period. A control analysis of nitrogen fractions was made immediately after sampling. The results of nitrogen analysis are entered in Table V as percentage of fresh weight and in Table VI as percentage of total nitrogen. The total amounts of carbon dioxide produced per gm. fresh weight are also given in Table VI. It is to be noted that the respiration measurements in the present investigation were made at long intervals to estimate the total amounts of carbon dioxide produced during the changes in the nitrogenous compounds of the exposed disc. From the data presented here it is not possible to show the respiration time curve,

TABLE V

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control fresh wt. 13·04 gm.	0·2212	0·1648	0·0564	0·0771	0·0428	0·0343	0·0534
Short period 65 hours fresh wt. 13·62 gm.	0·2436	0·1428	0·1008	0·0684	0·0376	0·0308	0·0436
Long period 138 hours fresh wt. 12·97 gm.	0·2184	0·1056	0·1128	0·0473	0·0235	0·0238	0·0345

TABLE VI

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N	Total CO_2 mg. produced per gm. fresh wt.
Control . . .	74·50	25·50	34·86	19·35	15·51	24·13	..
Short period . .	58·62	41·38	28·08	15·44	12·64	17·90	4·375
Changes from the control	—15·88	+15·88	—6·78	—3·91	—2·87	—6·23	..
Long period . .	48·35	51·65	21·66	10·76	10·90	15·79	..
Changes from the control	—26·15	+26·15	—13·20	—8·59	—4·61	—8·34	10·701

the precise elucidation of which would necessitate a much modified technique so as to give frequent readings over small time intervals under controlled temperature conditions. At the end of short period considerable changes in the nitrogen content of the discs have occurred. There is a net gain in protein in both the periods, larger amount being synthesized at the end of long period. It is noticed that as between amino-acids and amides there is always more decrease in the former.

Surface-volume effects in nitrogen metabolism

Experiment IV. The surface : volume effects in respiration have been studied by Steward, Wright and Berry [1932] in detail. With discs of variable dimensions they have shown that the respiration of potato discs in air or immersed in liquid is not uniform throughout their mass, but the cells at the external surface in contact with free oxygen, either dissolved in water or present in a gaseous phase, contribute relatively much more carbon dioxide to the total than those in the interior. By using a wide range of thickness variation from 0·3 mm. to 19·7 mm. a quantitative measurement of the zone of high respiration and the inactive zone of tissue respiring at a normal rate has been made by Steward [1932].

In view of the surface-volume effects in respiration, the present experiment is made to observe the effect of thickness variation on the nitrogen metabolism. It may be mentioned that in the present experiment no attempt has been made to differentiate between the amount of carbon dioxide produced from the zone of high respiration and from the inactive zone and thus to correlate the increased carbon dioxide production with the changes in the nitrogenous compounds ; the precise computation of which would necessitate the use of discs thinner than those used here, namely 5 and 10 mm.

Duplicate series of 5 and 10 mm. thickness discs are allowed to respire in the respiration chamber periodical supply of water to the evaporating cells is maintained as mentioned before. The temperature recorded in the thermograph varied between 13° to 21° C. The respiration rates are presented in Tables X and the nitrogen analysis of the discs are given in Table VII and VIII. Each series is provided with its own control analysis.

TABLE VII

Nitrogen as percentage of fresh weight

—	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
5 mm. thick control fresh wt. 25·30	0·2087	0·1407	0·0680	0·0736	0·0437	0·0399	0·0272
A fresh wt. 25·56 .	0·2068	0·1287	0·0781	0·0651	0·0356	0·0295	0·0341
10 mm. thick control fresh wt. 25·22	0·2188	0·1621	0·0567	0·0753	0·0350	0·0403	0·0465
B fresh wt. 23·49 .	0·2198	0·1583	0·0615	0·0737	0·0316	0·0421	0·0425

TABLE VIII

Percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
5 mm. thick control	67·42	32·58	35·27	16·15	19·12	13·03
A	62·23	37·73	31·48	17·22	14·26	16·49
10 mm. thick control	74·09	25·91	34·41	15·99	18·42	15·22
B	71·97	28·03	33·53	14·36	19·15	19·29

The changes in nitrogen content as noticed between 5 and 10 mm. thickness are compared with those of 3 mm. thickness of Experiment III (long period), which was performed under the same experimental condition and the results of comparison are presented in Table IX.

TABLE IX

Changes in percentage of nitrogen content from the control values

—	Protein N	Amino-acid N	Amide N	Residual N
3 mm. thick Sp. surface 8·84 cm².	+26·15	—7·59	—4·61	—8·34
5 mm. thick Sp. surface 5·08 cm².	+5·15	+1·07	—4·86	+3·46
10 mm. thick Sp. surface 3·21 cm².	+2·12	—1·61	+0·73	+4·07

It is evident that the variation in the disc thickness between 3 and 5 mm. has resulted in a considerable difference in the nitrogen metabolism (Table IX). With 3 mm. there is a considerable increase in protein nitrogen accompanied by decrease in amino-acid, amide and residual nitrogen, while using 5 mm. thickness less increase in protein nitrogen with a reduction of amide and an increase in residual and amino-acid nitrogen is obtained. A still smaller increase in protein nitrogen is seen with discs of 10 mm. thickness. From the data presented in Table IX it is noticed that the change in the nitrogenous compound is more intense with 3 mm. thickness than with 5 mm., whose surface exposed to air per unit weight of tissue as referred specific surface in Table IX, is greater than that of 5 mm. thickness. Similarly between 5 and 10 mm. thickness small increase in protein nitrogen is associated with a small change in the specific surface.

The mean respiration rate of the discs showing such variation in the nitrogen changes are presented in Table X.

TABLE X

Variation in disc thickness and mean respiration rate

Thickness of the disc in mm.	Specific surface cm.²	Mean respiration rate mg. CO_2 per gm. fresh wt.
3	8·84	0·0668
5	5·08	0·0438
10	3·21	0·0382

It is noticed that the mean respiration rates between 3 and 5 mm. thickness differs considerably and also the nitrogen changes are great. By increasing the thickness from 5 to 10 mm. the respiration rate is low, the increase in protein nitrogen is small. When the mean respiration rates are considered in relation to the surface of the disc exposed per unit weight of the tissue (specific surface per gm. of tissue), it is found that the rates are related to the change in the specific surface as has been shown by Steward.

Effect of feeding ammonium nitrate

Experiment V. In view of the absorption of ammonium nitrate by the storage tissue and its possible utilization in the nitrogen metabolism of the discs, in this experiment the discs are supplied with ammonium nitrate. The experiment is started with six series, three are supplied with ammonium nitrate and three with distilled water, as in the previous experiment. Potatoes of the same variety grown in the following season are used soon after they are harvested. The concentration of ammonium nitrate used is 2·38 gm. per litre. Temperature variation during the length of the experiment

is from 21° to 30°C. Of the six series, two with water and two with ammonium nitrate are run for six days and the remaining two for nine days. Each series is provided with its own control analysis and in order to minimize the errors due to sampling the discs from the tubers are so selected that each individual disc in the series has its own control from the adjacent region of the tuber. Nitrogen analyses of the six series are presented in Table XI as percentage of fresh weight and the respiration rates are entered in Table XV. Absorption of ammonium nitrate in the discs of treatment A, B and C is considerabl and of this a greater amount is retained in the forr of crystalloid nitrogen. It is noticed that th nitrogen supply to the discs has considerably in creased all the nitrogen fractions with the excep tion of residual nitrogen in series A and C, whicl show a reduction. The statistical analysis (Tabl XIV) shows that this difference in A and C is no significant against the standard error. Thes changes are presented in Table XII as the per centage difference of nitrogen content from th respective control values.

TABLE XI

Nitrogen as percentage of fresh weight

Treatment	Total N	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
A. Control— Fresh wt. 16·16 gm.	0·2430	0·1707	0·0723	0·0890	0·0518	0·0372	0·0445
Ammon. nit. 6 days fresh wt. 14·23 gm.	0·3489	0·2702	0·0787	0·1584	0·0812	0·0772	0·0346
Changes from the control . . .	+0·1059	+0·0995	+0·0064	+0·0694	+0·0294	+0·0400	—0·0099
B. Control— Fresh wt. 14·30 gm.	0·2552	0·1745	0·0807	0·0923	0·0474	0·0449	0·0373
Ammon. nit. 6 days fresh wt. 14·19 gm.	0·4351	0·3355	0·0996	0·1740	0·0807	0·0933	0·0682
Changes from the control . . .	+0·1799	+0·1610	+0·0189	+0·0817	+0·0333	+0·0484	+0·0309
C. Control— Fresh wt. 14·40 gm.	0·2510	0·1676	0·0834	0·0877	0·0473	0·0404	0·0395
Ammon. nit. 9 days fresh wt. 13·34 gm.	0·4992	0·3706	0·1286	0·1936	0·0542	0·1394	0·0376
Changes from the control . . .	+0·2482	+0·2030	+0·0452	+0·1059	+0·0069	+0·0990	—0·0019
D. Control— Fresh wt. 14·55 gm.	0·2521	0·1789	0·0732	0·0951	0·0574	0·0377	0·0461
Water 9 days fresh wt. 14·60 gm. .	0·2549	0·1554	0·0995	0·0649	0·0275	0·0374	0·0531
E. Control— Fresh wt. 15·57 gm.	0·2485	0·1674	0·0809	0·0913	0·0592	0·0339	0·0423
Water 6 days fresh wt. 14·50 gm. .	0·2485	0·1533	0·0952	0·0730	0·0342	0·0388	0·0415
F. Control— Fresh wt. 14·92 gm.	0·2642	0·1765	0·0877	0·0930	0·0557	0·0373	0·0462
Water 6 days fresh wt. 14·40 gm. .	0·2537	0·1545	0·0992	0·0670	0·0297	0·0373	0·0502

TABLE XII

Difference in percentage of nitrogen content from the control values

Treatment	Total N	Total cryst. N	Protein N	Amino-acid N	Amide N	Residual N
Ammon. nitrate— 6 days A	+43·58	+58·29	+8·85	+56·76	+107·53	—22·25
6 days B	+69·71	+92·26	+23·42	+70·25	+107·80	+82·84
Ammon. nitrate— 9 days C	+98·88	+121·12	+54·20	+14·59	+254·04	—4·81

The synthesis of protein as a result of nitrogen supply is noteworthy. In both A and B after six days there is an increase in protein nitrogen, the increase is more in B which has absorbed more nitrogen. It is clear that feeding with ammonium nitrate has greatly increased the amino-acid content of the discs in A and B. The amide nitrogen figures presented here show a considerable increase, but it should be remembered that it also includes the free ammonia that has been absorbed by the discs and remains unmetabolized. In B a very high increase in the residual nitrogen is noticed which is also statistically significant (Table XIV), and this is possibly due to nitrate nitrogen. A comparison between A and B (Table XII) shows the same percentage increase in amide nitrogen (which estimates free ammonia) after nitrogen supply, while the percentage increase differs in total crystalloid nitrogen, B has absorbed more nitrogen. This increase in B from A in total crystalloid nitrogen is not as free ammonia as otherwise a similar increase would be expected in the residual nitrogen as nitrate nitrogen. After nine days the discs (C) have absorbed still more nitrogen and the synthesis of protein is also further increased. Of the total nitrogen absorbed a considerable portion is in soluble form. The increase in amino-acid nitrogen is maintained, but the increase is much less as compared with the values in A and B and this connected with the fact that in C a considerable amount of protein is synthesized and in this synthesis possibly the amino-acids have been utilized. The amide nitrogen including free ammonia shows a very large increase at the end of nine days, the difference in the residual nitrogen is however quite insignificant.

The series D, E and F which received water only show a very striking result in the synthesis of protein. Nitrogen fractions of these series with their respective control analyses are presented in Table XIII as percentage of total nitrogen.

TABLE XIII

Nitrogen as percentage of total nitrogen

—	Total cryst. N	Protein N	Total amino N	Amino-acid N	Amide N	Residual N
Control	70·96	29·04	37·72	22·77	14·95	18·32
9 days, water D	60·97	39·03	25·46	10·77	14·69	20·73
Control	67·36	32·64	36·74	23·10	13·64	16·99
6 days, water E . . .	61·69	38·31	29·38	13·77	15·61	16·75
Control	66·81	33·19	35·20	21·08	14·12	17·49
6 days, water F . . .	60·90	39·10	26·41	11·71	14·70	20·43

In the series E and F supplied with water for six days, there is an increase in protein nitrogen with a decrease in amino-acid nitrogen. The discs supplied with water for nine days have synthesized more protein nitrogen than those after six days. The amino-acid nitrogen has diminished to a great extent while the changes in amide and residual nitrogen are small. From the results presented here it is evident that the synthesis of protein has taken place with the disappearance of amino-acid. This increase in protein nitrogen at the expense of amino-acids is also statistically singnificant, while the variations in amide and residual nitrogen are not significant (Table XIV). A comparison between the series receiving ammonium nitrate and the series D, E and F supplied with water only show that the nitrogen absorption in the former has resulted in greater increase in protein nitrogen than in the latter.

The data in this experiment were subjected to the statistical analysis and the standard errors for different nitrogen fractions were calculated from the six control series (Table XI). The mean differences of the nitrogen content after the treatment were tested against the standard errors. The results are presented in Table XIV. (Since the residual nitrogen is estimated from the difference between the total crystalloid nitrogen and the sum of amino and amide nitrogen, its standard error is calculated from the sum of the standard errors of total crystalloid, amino and amide nitrogen).

TABLE XIV

Statistical analysis

—	Total N	Total cryst. N	Protein N	Amino-acid N	Amide N	Residual N
Differences from mean :						
A	*+0·0966	*+0·0976	*—0·0010	*+0·0281	*+0·0386	+0·0077
B	*+0·1828	*+0·1629	*+0·0199	*+0·0276	*+0·0547	*+0·0259
C	*+0·2469	*+0·1980	*+0·0489	+0·0011	*+0·1008	—0·0047
D	+0·0026	*—0·0172	*+0·0198	*—0·0256	—0·0012	+0·0108
E	—0·0038	*—0·0193	*+0·0155	*—0·0189	+0·0002	—0·0018
F	0·0014	*—0·0181	*+0·0195	*—0·0234	+0·0013	+0·0079
Mean of six controls	0·2523	0·1726	0·0797	0·0531	0·0386	0·0423
Variance	0·0000505	0·0000228	0·0000354	0·0000261	0·0000139	..
Standard error	±0·0030	±0·0020	±0·0025	±0·0021	±0·0016	±0·0057

It is apparent that the total nitrogen and the total crystalloid nitrogen have increased significantly as a result of ammonium nitrate supply. The increase in protein nitrogen in all the series except A is highly significant. (In A the increase in protein nitrogen from its own control is more than twice the standard error). Highly significant variation in amino-acids as the result of nitrogen supply and also in the resynthesis of protein is beyond doubt. The amide nitrogen increase due to the supply of ammonium nitrate is highly significant. The differences in the residual nitrogen in general are not significant except in B where a high value is noticed possibly due to nitrate nitrogen as explained before. From the statistical analysis it is clear that the data noted in this experiment indicate a real difference in the nitrogen metabolism as a result of nitrogen supply and also in the resynthesis of protein at the expense of amino-acids.

The respiration rates of these six series are measured after long intervals and the rates are presented in Table XV as mg. of carbon dioxide per gm. fresh weight per hour.

It is noteworthy that along with the absorption of ammonium nitrate in A, B and C there is an increase in the respiration rates. The series receiving ammonium nitrate always show a higher respiration rate than those receiving water only. The rates (C and D) show minor fluctuations in the initial stage and then gradually fall in both treatments, the fall being rapid in D which was supplied with water only. The high level of respiration rate as a result of nitrogen supply reflects the relationship of amino-acids to the respiration rates of Spoehr and McGee

TABLE XV

Respiration rates—mg. of carbon dioxide per gm. fresh weight per hour

—	A Ammon. nitrate	B Ammon. nitrate	E Water	F Water	C Ammon. nitrate	D Water
Period—						
46 hours	0·1294	0·1245	0·1240	0·1097	0·1472	0·1194
92 hours	0·1168	0·1372	0·1010	0·0944	0·1332	0·0991
138 hours	0·1380	0·1400	0·1270	0·0990	0·1457	0·1084
184 hours	..	..	..	..	0·1256	0·0815
206 hours	..	..	..	..	0·1214	0·0726
Mean	0·1281	0·1339	0·1173	0·1010	0·1346	0·0962

[1923] who suggested the accelerating effect of amino-acids on respiration rates. Nitrogen supply has increased the amino-acid content and this possibly maintains the respiration rate high. On this hypothesis of Spoehr and McGee the respiration rate falls in D as the amino-acids disappear in the synthesis of protein.

Table XVI shows the total amount of carbon dioxide produced and the increase in protein nitrogen over the respective controls after the end of the respiration periods.

TABLE XVI

Production of CO_2 and increase in protein nitrogen

—		Total CO_2 in mg. produced per gm. fresh wt.	Increase in mg. of protein-N per gm. fresh wt.	Rate of increase in protein-N per mg. of CO_2 respired
Ammon. nitrate 138 hours (6 days approx.)	A	17·6732	0·064	0·0036
	B	18·4736	0·189	0·0102
Ammon. nitrate 206 hours (9 days approx.)	C	28·0490	0·452	0·0163
Water 206 hours	D	20·3836	0·263	0·0133
Water 138 hours	E	16·1920	0·143	0·0088
Water 138 hours	F	13·9426	0·115	0·0083

DISCUSSION

The results presented in this investigation indicate a profound change in the nitrogen substances as a result of increased metabolic activities at the cut surfaces of potato discs. The potato tuber contains a very high percentage of soluble nitrogen–about 79 per cent in the tubers examined; of this a very considerable portion is synthesized into protein when the dormant cells of the tubers are brought to a condition facilitating gas exchange.

The increase in protein nitrogen is related to the oxygen supply as may be seen from the results of experiment I. Under aerobic condition protein content is increased by 22 per cent of total nitrogen while under anaerobic condition 3 per cent is formed. It is interesting, however, that even under these conditions there is a net gain in protein. Temperature appears to play an important part in determining protein synthesis since in experiment II performed at constant temperature 25° C., there is a loss of protein under both conditions and greater loss in protein occurs under aerobic condition. In this case the protein nitrogen has apparently formed residual nitrogen whereas under anaerobic condition there is a large increase in amino-nitrogen. Steward, Wright and Berry [1932] have drawn attention to the effect of the thickness of disc in determining respiration per gm. fresh weight of the disc. They conclude that the active respiring zone is confined to the surface layer of disc, while the inner tissue continues to respire at a normal rate of the uninjured tuber. Experiments on the thickness of disc reported above completely confirm their findings.

The protein synthesis occurs in conjunction with the development of a cork meristem and occurs at the surface only. It might be expected therefore that either (1) the protein synthesis per disc is independent of the thickness of the disc or (2) that the thicker disc would show higher protein synthesis per disc. The first alternative would indicate that oxygen supply is the chief factor in protein synthesis while the second would indicate that mobilization of nitrogen from the deeper layers is important and therefore the thicker disc containing a large reservoir of nitrogen would also show greater synthesis. The data for change in nitrogen fractions as percentage of total nitrogen present as related to disc thickness have been presented in Table XVII. It is seen that the percentage increase in protein is greatest in the thinner disc and rapidly decreases with the thicker disc. Calculated on the basis per disc the increase in protein nitrogen is shown in Table XVII. The total amount of carbon dioxide production on the same basis are entered for comparison.

TABLE XVII

Relation of protein synthesis to disc thickness and respiration

Disc thickness in mm.	Disc weight gm.	Increase in protein-N per disc	Total amount of CO_2 produced per disc per hour
3	2·16	0·00122	0·1443
5	4·26	0·00043	0·1866
10	7·83	0·00037	0·2991

It now appears that the absolute amount of protein is inversely related to the thickness of the disc and to carbon dioxide production. The relation of protein synthesis to disc thickness is

therefore quite different from that of respiration. Question arises as to the cause of the lower protein synthesis in the thicker discs. These have slightly larger surface and larger reserve of nitrogen and therefore neither oxygen supply nor nitrogen reserve will account for the results obtained. The higher carbon dioxide production of the thicker disc is due to the fact that the internal tissues contribute to the carbon dioxide produced. Starch hydrolysis occurs at a layer extending beyond the meristematic region and it is possible that in the thicker disc of sugar formed only a part diffuses to the meristem whereas remainder diffuses into the deeper layers. In the thinner disc therefore all sugar produced by hydrolysis of starch is available for protein synthesis, whereas with thicker disc proportionately less sugar is available for meristem and more is lost in the deeper tissue. That diffusion into deeper layers occurs is shown by Steward's experiments on bromide accumulation. The whole question requires further investigation.

So far condition affecting the nitrogen changes have been discussed and in these changes it has been observed that the increase in protein nitrogen is accompanied by the disappearance of amino-acids. The values for the increase in protein nitrogen and the changes in amino-acid, amide and residual nitrogen are entered in Table XVIII.

Table XVIII

Nitrogen as percentage of total nitrogen

Experiment No.	Protein N	Amino-acid N	Amide N	sidual N
I. Control . .	21·08	16·56	19·19	23·98
7 days . .	+22·16	—8·07	—6·22	—0·66
III. Control . .	25·50	19·35	15·51	24·13
3 days F . .	+15·88	—3·91	—2·87	—6·23
6 days E . .	+26·15	—8·59	—4·61	—8·34
V. Control . .	32·92	22·09	13·88	17·24
6 days . . .	+5·79	—9·35	+1·28	+1·35
Control . . .	29·04	22·77	14·95	18·32
9 days . . .	+9·99	—12·00	—0·26	+2·41

It is seen that the increase in protein nitrogen is always accompanied by the disappearance of amino-acids. This loss in amino-acids in the potato discs may be due to two reasons (1) either the amino-acids are resynthesized back to protein by condensation or (2) it is due to the oxidative deamination to produce ammonia which unites with the carbohydrates to form protein. Since it has been shown by the author [Sircar, 1936] that deamination does not depend on the concentration of carbohydrates present, there is the possibility of deamination in the potato discs as a consequence of increased metabolic activities. An argument against the first reason may be suggested, namely that if the loss in amino-acids were directly responsible for the condensation of amino-acids to protein, then the greatest loss in amino-acids would be found in those cases where the greatest increase in protein nitrogen is attained. This is not the case. Table XVIII shows that in experiment V the loss in amino-acids is greater than in experiments III or I, where more protein is synthesized. Since the loss in amino-acids is not equivalent to the protein formed, it must mean that loss has occurred the other way by oxidative deamination. Further, it is also evident that the loss of amino-acids is more in those cases where there is more production of carbon dioxide. The amount of carbon dioxide produced and the loss in amino-acids in the series receiving water in two experiments are shown in Table XIX.

Table XIX

Production of CO_2 and loss in amino-acid nitrogen

——	Total CO_2 mg.	Loss in amino-acid N mg.	Loss in mg. per mg. of CO_2
Experiment III E .	10·70	0·193	0·018
Experiment V E & F	15·0673	0·255	0·017

A comparison between experiments III and V shows that in the latter an increased carbon dioxide production accompanies a greater loss in amino-acids than in experiment III. The increased carbon dioxide production must have occurred through the greater loss in amino-acids since the carbohydrate supply in both the cases is the same. Under anaerobic condition it has been shown that the synthesis of protein is small and has increased to the same extent as the amide has disappeared (Table II).

It is seen that the amino-acids have not disappeared, on the contrary, there is an accumulation from proteolysis. This increase in amino-acids shows that there is no deamination, otherwise either the amino-acids would have been lost or the ammonia set free during the process would be free or form amide and the level of amide nitrogen would have been raised further. Since it is found that the increase in protein nitrogen is only equal in extent to the disappearance of amide this may mean that in absence of deamination the synthesis of amide is inhibited and consequently protein level is not increased. Hence from these considerations it may be suggested that the amino-acids are not resynthesized into protein, the disappearance is due to the oxidative deamination, which sets free ammonia to form

the amide, and from the amide the protein is synthesized.

The supply of inorganic nitrogen to the potato disc has resulted in an accumulation of nitrogen (Tables XI and XII) and metabolic activities of these cells as measured from the increased carbon dioxide production are also increased (Table XVI). It is seen that a considerable portion of absorbed nitrogen remains in the soluble form. The synthesis of protein from the addition of inorganic nitrogen is shown. The absorption of nitrogen and the synthesis of protein from this added nitrogen increased with time. As compared with six days the protein nitrogen and the soluble nitrogen have both increased at the end of nine days (Table XII, C). Since no separate estimations of nitrate nor ammonia were made, nothing could be said from the data presented as to the relative absorption of anion and cation. In series A and C (experiment V) receiving ammonium nitrate, there is no increase in residual nitrogen which includes the presence of nitrate nitrogen. It means that either nitrate has not been absorbed or has been used up in metabolism. In B (Table XII) the increase in residual nitrogen is shown and is explained to be possibly due to nitrate nitrogen. From this it may be said that nitrate also is absorbed in A and C, and has been metabolized. The course of amide metabolism in the series receiving ammonium nitrate is not exactly known as the amide figures presented here include the possibilities of unmetabolized ammonia. The amino-acids in these three series show a remarkably higher value than the series not receiving extra nitrogen (Table XI). The increased amino-acids are possibly due to the accumulation of amino-acids derived from proteolysis. In these series the metabolic activities of the cells are increased as evident from the enhanced carbon dioxide production (Table XVI). In response to this the process of synthesis would be expected to increase and this increase in the synthesis is noticed from a reference to Table XVI (B and C) where it has been shown that the increase in protein nitrogen per mg. of carbon dioxide respired is greater than the corresponding series receiving water only. As the synthesis is increased the proteolysis would also be expected to have increased since these two processes occur concurrently. The increase in amino-acids may thus be explained in the discs receiving added nitrogen.

Summary

An apparatus is designed to maintain simultaneously the necessary conditions for allowing discs of potato tuber to respire aerobically for a considerable time in an atmosphere free from carbon dioxide accumulation, and for salt absorption and water supply to the transpiring cells without interfering with aeration and carbon dioxide measurement during the course of an experiment.

Discs of potato tuber (var. King Edward VII) contain a high percentage of soluble nitrogen—a maximum of 79 per cent of total nitrogen in the tubers examined ; of this a considerable portion is synthesized to protein when the dorment cells of the tuber are exposed to a condition of free gas exchange. The increase in protein nitrogen is related to oxygen supply and increased carbon dioxide production.

In the synthesis of protein the behaviour of nitrogen fractions, namely amino-acids and amides, have been studied. That the disappearance of amino-acids in protein synthesis is due to the process of oxidative deamination to set free ammonia to form amide which synthesizes protein has been suggested.

Absorption of inorganic nitrogen and metabolism of this into protein and other soluble organic nitrogen have been noted in the discs. These changes are accompanied by increased respiration rate.

Acknowledgements

The author desires to express his gratitude to Prof. V. H. Blackman, Sc.D., F. R. S., for granting facilities to carry out this investigation at the Imperial College of Science and Technology, London, and to Prof. F. G. Gregory, D.Sc., F. R. S., for suggesting the problem, continued inspiration and encouragement.

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A CANKER OF APPLE TREES IN MYSORE

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(Received for publication on 17 September 1942)

(With Plate XVI)

TWIGS of young apple (*Pyrus Malus* L.) trees affected by a canker were recently sent by the Director of Horticulture, Mysore State, for determination of the causal organism. The plants were imported from Australia and the canker appeared on them within a fortnight of receipt. The canker is due to a fungus known to pathologists as *Sphaeropsis Malorum* Berk. which has been recorded for India by Butler and Bisby [1931]. Specimens of cankered pear (*Pyrus communis* L.) twigs from Kumaon, recently deposited in the Herb. Crypt. Ind. Orient. by Mr U. B. Singh, Research Assistant Mycologist, Chaubattia, also bear the name '*Sphaeropsis Malorum* (*Haplosporella*)', but without authorities. As there is some confusion in the nomenclature of the fungi belonging to the genus *Sphaeropsis* and causing cankers in apples and pears and as *Sphaeropsis Malorum* Berk. has evidently been introduced into Mysore with the apple stocks from Australia, its record for India by Butler and Bisby [1931] being based on an error, a description of the fungi causing the canker is reported in this note.

There are two distinct fungi bearing the name *Sphaeropsis Malorum*, viz. *S. Malorum* Berkeley and *S. Malorum* Peck, and though these names have been superseded by the names applied to their perfect (ascus) stages, they persist among pathologists because of their long and constant usage in pathological literature. The name was first applied by Berkeley in 1836 to a fungus found by him in decayed apples in England and Peck used it, with Berkeley as authority, for a fungus causing a black rot of apples in New York State. The spores of Berkeley's fungus were hyaline while those of Peck's were brown. Saccardo accordingly renamed Berkeley's fungus *Phoma Malorum* (Berk.) Sacc. and used the name *Sphaeropsis Malorum* for the New York fungus, citing Peck as the authority. This manner of changing names is in contravention of the Rules of Botanical Nomenclature as at present understood and this has led to considerable confusion. The discovery of the perfect stages of these two fungi by N. E. Stevens [1933, 1936] and a careful examination of the type specimens of the related fungi by him and by Petrak and Sydow [1926] have helped a great deal in stabilizing the nomenclature of these fungi. It may be added that the genus *Sphaeropsis* itself has been partly merged into *Haplosporella* and partly into *Botryodiplodia*, as a synonym.

Both the fungi have identical stromatic characters but they show constant differences in the characters of the pycnospores. The spores within the pycnidium in Berkeley's fungus are hyaline, non-septate, and relatively thick-walled, walls appearing glassy under the microscope. They are regular in shape and according to N. E. Stevens [1933], measure $22\text{-}33 \times 9\text{-}13\mu$, mostly $23\text{-}29 \times 9{\cdot}5\text{-}10\mu$. When the cankered twigs are incubated, the pycnidia burst out of the cortical parenchyma in which they are embedded and slender spore tendrils are exserted out of the ostiole, at which time the spores become brown or tan coloured and 1-septate and measure $20\text{-}27 \times 10\text{-}16\mu$, mostly $25\text{-}27 \times 10\text{-}12\mu$ (Stevens) (Plate XVI, fig. 3).

As against these characters, the spores of Peck's fungus are uniformly tan to brown within the pycnidium itself and as a rule irregular in shape. A small percentage may be 1-septate but there is no difference in the colour of the septate and non-septate spores. Stevens [1933] gives the measurement as $24\text{-}30 \times 12\text{-}18\mu$, mostly $25\text{-}27 \times 12\text{-}13\mu$. (Plate XVI, fig. 4).

It will be noted that the chief differences between the two fungi are in the shape, size, septation and particularly the time of colouring of the spores. This difference in the time of colouring is so constant that Petrak and Sydow [1926] consider it the most reliable diagnostic character for distinguishing *Botryodiplodia Malorum* (Berk.) Petr. and Syd., the name applied by them to Berkeley's fungus, from *Haplosporella Mali* (Westend.) Petr. and Syd., the name given to Peck's fungus. It may be further added that all these names are now superseded by the names applied to the ascus stage which according to N. E. Stevens [1933, 1936] are *Physalospora mutila* (Fries) N. E. Stevens and *Physalospora obtusa* (Schw.) Cooke, respectively.

Sphaeropsis Malorum Berk., recorded by Butler and Bisby [1931] for India, is based on a report of its occurrence on a rotten apple by Mitter and Tandon [1929] who presumed that it came from Kulu. Of the two isolations made by them, one formed pycnidia in culture media. These were dark brown, immersed in the substratum and contained olive-brown, non-septate conidia of uniform size. The culture was submitted to Dr A. S.

Horne, Imperial College of Science, London, who is reported to have stated that it resembled '*Sphaeropsis Malorum*', but he was not definite as his own culture of the fungus was not sporing and an accurate comparison was not possible. It will be admitted that that is hardly enough evidence to record *Sphaeropsis Malorum* Berk. for India.

The fungus occurring on the Australian apple stocks in Mysore (Plate XVI, fig. 1) is undoubtedly Berkeley's fungus, for the pycnidia contained hyaline, large-granuled, regular-shaped spores with thick, glassy walls, which become tan or brown and 1-septate after being extruded out of the pycnidia (Plate XVI, fig. 3). They are slightly shorter and a little broader than the European form, the hyaline and non-septate spores being $14\cdot4$-$23\cdot4\times10\cdot8$-$14\cdot4$M and 1-septate and brown spores being $16\cdot2$-$23\cdot4\times9\cdot0$-$12\cdot6\mu$. It may be added that both the hyaline and the brown spores freely germinate within 24 hours if suitable conditions are provided and all attempts made so far to obtain the ascus state in culture have proved futile. Both *Sphaeropsis Malorum* Berk. and *Sphaeropsis Malorum* Peck have been recorded for Australia byNoble, Hynes, McCleery and Birmingham [1934], the latter being designated *Physalospora Cydoniae* Arnaud, on pears and apples respectively.

That the fungus is a new introduction from Australia on imported apple stocks is therefore more than likely. The Mysore fungus bears a certain resemblance to *Glutinium macrosporum* Zeller which according to Zeller [1927] causes a canker of apple and pear trees in Oregon. Its pycnidia are covered with a white, flaky exudate in dry weather, giving the black pycnidia a white sheen. When full grown, they are almost superficial. The conidiophores are simple or slightly branched as against the simple conidiophores in *Sphaeropsis Malorum.* The conidia are hyaline, 1-celled and exude at the apex, in the form of flinty, translucent globules and never become 2-celled or coloured.

A specimen of '*Sphaeropsis Malorum*' collected in the Nilgiris in 1915 is available in the Herbarium of the mycology section at Coimbatore. The specimen is at present without any conidia and it is not possible to say whether the identification is correct. A canker of pear trees is reported to be doing over 35 per cent damage in Kumaon (Plate XVI, fig. 2). The fungus responsible for that canker, specimens of which were kindly made available by Mr U. B. Singh, is not *Sphaeropsis Malorum* Berk. and it does not appear to be *Sphaeropsis Malorum* Peck, for though the spores are of the *Haplosporella* type, the fungus is intimately associated with its ascus stage which is not *Physalospora obtusa* but a fungus belonging to Cucurbitariaceae and is perhaps a species of *Otthia.* All efforts that were made to germinate the conidia which are always coloured, and the ascospores of this fungus have so far given negative results.

In a few infection experiments that were conducted, it was noted that the Mysore fungus can cause a severe rot of apple fruit and that it is able to attack twigs of pear.

We would like to express our thanks to Mr H. C. Javaraya, Director of Horticulture, Mysore State, for furnishing the specimens.

Summary

This note records the occurrence of *Sphaeropsis Malorum* Berk. [*Physalospora mutila* (Fries) N. E. Stevens] on imported apple plants in Mysore. It also shows that the previous records of the occurrence of this fungus in India are based on error.

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**Postscript*

Since the above was sent for publication, Mr. E. W. Mason of the Imperial Mycological Institute, Kew, wrote to say that the spores of the Mysore specimen of *Sphaeropsis* are consistently smaller than those of the European species of *Sphaeropsis Malorum* Berk. It was considered desirable, therefore, to compare the Mysore fungus with a specimen from Australia, which became possible through the courtesy of Dr C. J. P. Magee, who kindly sent two diseased twigs collected in Australia in 1925. A comparison indicates that both the Mysore and the Australian species are one and the same. The measurements of the unextruded spores are given below :

Type specimen, measurements by E. W. Mason : 23-28 $\times$ 10-12μ

Australian specimen, authors' measurements : $14\cdot4$-$23\cdot4\times9\cdot2$-$14\cdot4\mu$

Mysore specimen, authors' measurements : $14\cdot4$-$23\cdot4\times10\cdot8$-$14\cdot4\mu$

Because of these differences in the measurements of the type specimen and the Mysore specimen, Mr Mason is certain that the latter is not Berkeley's fungus. But there is little doubt that it is same as the Australian species. On the second twig sent by Dr Magee we have found perithecia and 8-spored asci, possibly the *Physalosprao* stage of the fungus. [Authors].

FIG. 1. Apple twigs affected by *Sphaeropsis Malorum* Berk. from Mysore (×2)

FIG. 2. Pear twigs affected by *Haplosporella* sp. and *Otthia* sp. from Kumaon (×2)

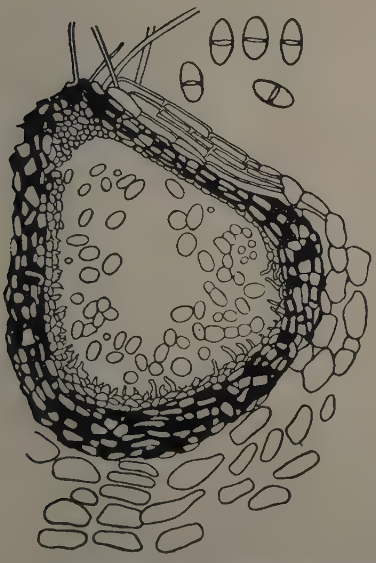

FIG. 3. Pycnidium of *Sphaeropsis Malorum* Berk. Hyaline 1-celled spores within and brown 2-celled spores outride

FIG. 4. Pycnidium of *Sphaeropsis Malorum* Peck after Hesler. (Note hyaline and brown spores which are irregular in shape)

Graduated rod placed inside the *jowar* crop for measuring its height

STUDIES ON THE ESTIMATION OF GROWTH AND YIELD OF *JOWAR* BY SAMPLING *

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(Received for publication on 14 October 1942)

(With Plate XVII and four text-figures)

In the past agricultural and meteorological statis-cs were collected mainly for certain general dministrative and technical purposes respectively. Vhile useful for those purposes, these data have roved to be inadequate for a detailed examination f the effect of weather on the development and ield of a crop. It is now realized that more precise timations of the crop's growth characteristics nd yield on the one hand and measurements of the ctual local or micro-climate of the crop on the ther are necessary if real progress is to be made in gricultural meteorology.

The simultaneous recording of the growth and ne 'micro' or local climate of a crop naturally ad to await the recent advances in (1) the methods f random sampling as applicable to the estima-on of crop growth and yield and (2) the new cience of micro-climatology or the meteorology f the air and soil layers very near the ground sur-ce in which crops have their existence.

Since 1929, under the inspiring leadership of rof. R. A. Fisher the application of modern atistical methods to the problems of estimating ne growth characters and yield of crops has made apid strides. A number of workers, e.g. Clapham 929 ; 1931], Kalamkar [1932], Yates and Zaco-anay [1935], Barnard [1936], Fairfield Smith 938] and very recently Hudson [1939 ; 1941] have nade numerous important contributions to the ubject in Great Britain.

It is clear that, for a short cereal crop like wheat, ne sampling technique developed in Britain will equire only slight modification to suit Indian onditions. On the other hand, in India, we have o deal with many tall crops like *jowar*, sugarcane, tc. and for such crops a suitable sampling tech-ique has to be evolved.

Since 1932, the Agricultural Meteorology Section as been engaged in developing suitable sampling echnique and recording precision observations n important Indian crops. Kalamkar and Gadre 1936] recorded precision observations on wheat t Poona. They found (1) the plant number in ne field at the time of harvest was only about 16 per cent of the number of seeds sown (2) Tillering reached the maximum value of 5·3 shoots to each plant but before harvest this came down to 4. (3) About 90 per cent of the shoots had put forth earheads before harvest and the average number of ears per plant was 3·5. (4) The estimated yields of grain and straw were 25·5 gm. and 49·0 gm. per metre respectively while the actual yields were 23·3 gm. and 50·5 gm. respectively.

Some crop-cutting experiments on the estimation of wheat yield by sampling were conducted by the Agricultural Meteorology Section with the kind co-operation of the Deputy Director of Agriculture, Jubbulpore, at the Government Experimental Farm, Powarkheda, Central Provinces. It was found that a unit of the order of 16 square yards appears to be suitable for sampling operations on wheat. It was also found that there is no material gain in information by sampling more than about 16 per cent of the crop and that the units elongated across the rows are less variable than those elongated along the rows. The data are being discussed in detail in another paper to be published shortly. The Agricultural Meteorology Section also conducted precision observations on rice (a short crop) at Karjat for the last seven years with the kind co-operation of Dr B. S. Kadam, Crop Botanist to the Government of Bombay. A paper discussing the results obtained is under publication. The important findings may, however, be briefly stated here. The number of culms increases and attains a maximum value by the sixth or seventh week after transplantation, remains more or less constant for about a fortnight and then decreases due to some of the late-formed tillers dying out. The period of quickest growth of the crop as indicated by its height is from the 8th to the 13th week after transplantation. The height attains its maximum value by the 13th week and remains constant thereafter. The percentage differences between actual and estimated yields are in general quite small.

In the present paper we shall discuss the results of some preliminary sampling experiments on *jowar*, a tall crop.

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* Summary of a thesis for the M.Sc. degree sub-nitted to the University of Madras

Precision observations on *Jowar*

Materials and methods. All the observations were taken on the *jowar* crop grown in the Agricultural College Farm, Poona. In 1940 germination observations were taken in *kharif jowar* (Nilwa variety). Developmental observations and harvesting experiments were done with *rabi jowar* (variety—Shalu Maldandi) during the clear seasons of 1940-41 and 1941-42. In all experiments the crop was studied by the method of random sampling, fresh samples being selected on each occasion. About 5 per cent of the crop was selected for each day's observation.

The 'sampling unit' consisted of two constituent one-metre lengths along a row separated by an interval of half-a-metre. The measuring rod was of the form shown below :

1 metre	½ metre	1 metre
observe	omit	observe

To facilitate the recording of observations, three inch nails at the end of each metre were projected horizontally to mark out individual metres exactly.

The following observations were taken on the plants in each metre length :

(*a*) Germination. The number of seedlings visible above the ground.

(*b*) Developemental observations :

(*i*) number of plants,
(*ii*) number of shoots,
(*iii*) number of fully expanded green leaves,
(*iv*) height of shoots up to the base of the fully expanded topmost leaf, and
(*v*) number of emerged earheads.

The field was sub-divided into four plots and 20 samples (i.e. 40 metre lengths) were taken from each plot so that the total number of metre lengths for each day of observation was 160. The allocation of the degrees of freedom was as follows :

Plots	3
Between samples	76
Within samples (between metres) . .	80
Total .	159

The analysis of variance for the number of shoots on 23 October 1940 is given in Table I to illustrate the method of analysis followed. Sampling error of the mean was obtained by taking the square root of the variance 'between samples' after dividing it by the total number of metres (160 in this case) under observation.

TABLE I

Analysis of variance for number of shoots per metre
(Observations on 23 October 1940)

Factor	Degrees of freedom	Variance
Plot	3	92·5
Between samples . .	76	117·2
Within samples . .	80	47·6
Total .	159	81·7

Sampling error for the mean =

$$\sqrt{\frac{117\cdot 2}{160}} = 0\cdot 855$$

(*c*) Harvesting experiments. For the estimation of the yield by sampling another structure of the sampling unit was also tried in addition to the one used in developmental studies as described above. This second method consisted in selecting two parallel metre lengths one from each of two adjacent rows to constitute one sampling unit as shown below :

$$\left.\begin{array}{ll}\text{One row} & 1\ \text{metre}\\ \text{Adjacent row} & 1\ \text{metre}\end{array}\right\}\ \text{under observation.}$$

This method will be called the 'parallel' method for convenience. When the crop was ready for harvest, samples were cut, bundled into sheaflets and dried. The dry weights of straw and of grain from each ultimate unit (metre in this case) of the sample were recorded and analyzed statistically.

(*d*) In 1941-42 in addition to the above experiments 110 individual plants were selected at random and bagged soon after setting. Height of plants as well as the diameter at one-fourth, half and three-fourths heights were measured when the crop appeared to be fully grown. When the crop was ready for harvest, the selected plants were cut close to the ground and weighed individually. Grains were removed and the weight of grain recorded.

Discussion of growth records

(*a*) *Germination study in* kharif jowar. The crop was sown on 6 July 1940 and germination counts were taken between 10 and 22 July. Table II gives the mean number of germinated seeds per metre together with the sampling error of the mean.

The sampling error of the mean =

$$\sqrt{\frac{\text{Variance between samples}}{\text{Total number of metres}}}$$

TABLE II

Mean values of germinated seeds and sampling error of the mean

(Sown on 6 July 1940)

Date	Mean per metre	Sampling error of the mean
10 July 1940 . .	8·700	0·403
11 ,, ,, . .	13·125	0·688
12 ,, ,, . .	12·963	0·724
13 ,, ,, . .	14·025	0·642
17 ,, ,, . .	15·719	0·738
18 ,, ,, . .	14·213	0·548
22 ,, ,, . .	14·481	0·642
1 Aug. ,, . .	10·350	0·435

Fig. 1 shows graphically the mean number of eedlings per metre length of row on each day.

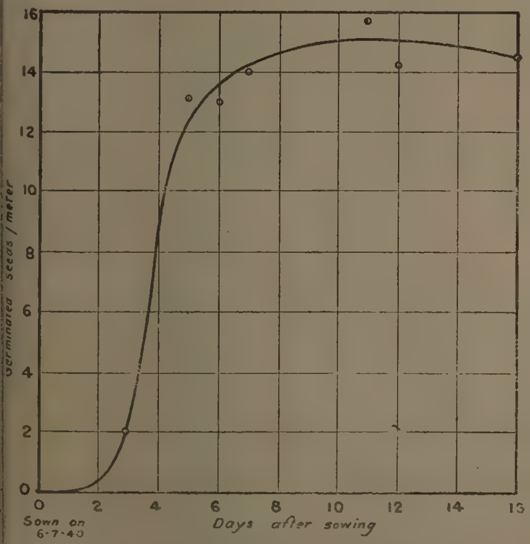


FIG. 1. Variation of number of germinated seeds per metre

will be seen from Fig. 1 that the maximum umber of germinated seeds is 15·72 as compared . 23·7 for 100 per cent germination. So the aximum germination percentage was only 66·3 nder field conditions, the remaining 33·7 being accounted for by non-viability or late or unsuccessful germination or loss due to birds and insects. The first seedlings made their appearance above ground on the third day after sowing and the number of germinated seeds increased abruptly on the fifth day indicating that 'the grand period' of germination comes between the fourth and sixth day after sowing. The daily increase in the number of seedlings before and after the above grand period was not found to be significant statistically. Twenty-seven days after sowing, the plant number came down to 10·35 per metre. It appears from Fig. 1 that 50 per cent of the maximum germination occurred 3 days 21 hours after sowing. This then is the period for germination according to the current convention.

There are three stages in the germination of the crop, (1) a period of slow germination, just after sowing, lasting for two to three days, (2) a period of rapid germination starting from the end of the first period and continuing till 11 days after sowing and (3) a gradual fall in the seedling number due to dying off of some of the weaker seedlings from crowded spots of the field.

The last column in Table II gives the sampling error as obtained by analyzing the data by the method indicated in Table I.

(*b*) *Growth of the crop*

Rabi *crop, 1940-41*. Table III shows the frequency distribution of the number of shoots per metre. The maximum value for each day is given in italics. It is interesting to observe the very wide fluctuation of shoot number per metre during the period of maximum tillering. At the end of this period the variability in the number of shoots per metre comes down.

Table IV gives the mean values of different plant attributes as well as the shoot to plant ratio together with sampling errors of the means. The variation with time of the mean values for the plant attributes is shown graphically in Fig. 2.

Plants. The estimated average number of plants per metre assuming 100 per cent germination is 69 while 35 days after sowing the actual number of plants per metre is only 7. This clearly shows that only 10 per cent of the total number of seeds sown survived as plants. The decrease in plant number from this date is not appreciable as is seen from the fact that after 89 days the mean number of plants per metre is 5·2. The decrease in plant number is accompanied by a slight fall in sampling error.

Shoots. Thirtyfive days after sowing the shoot number was 14·77. This fell to 6·90, 80 days after sowing. This fall is fairly uniform with respect to time as seen from Fig. 2. The sampling error also shows a tendency to fall The shoot to plant ratio was 2 on 28 October 1940 and came down to 1·3 on 21 December 1940

TABLE III

Rabi jowar *1940-41*

The frequency distribution of the number of shoots per metre

Days after sowing	Date	Number of shoots per metre																		Mean No. of shoots per metre	Remarks
		0-2	3-5	6-8	9-11	12-14	15-17	18-20	21-23	24-26	27-29	30-32	33-35	36-38	39-41	42-44	45-47	48-50	51-53		
30	23 Oct. 1940 .	5	14	16	17	27	22	22	18	5	5	2	4	2	0	1	0	0	0	13·53	Maximum tillering
35	28 ,, ,, .	10	19	13	15	33	27	13	12	8	5	0	0	3	0	1	1	0	0	14·17	
43	5 Nov. ,, .	13	17	27	21	22	17	17	9	8	4	3	1	0	0	0	0	0	1	12·75	
53	15 ,, ,, .	17	27	32	28	24	9	11	6	5	1	0	0	0	0	0	0	0	0	9·83	
60	22 ,, ,, .	12	33	30	23	23	16	9	7	4	0	1	0	2	0	0	0	0	0	10·41	
72	4 Dec. ,, .	29	26	37	29	16	11	6	3	2	0	0	0	0	0	1	0	0	0	8·36	
80	12 ,, ,, .	28	42	38	22	22	6	0	1	1	0	0	0	0	0	0	0	0	0	6·90	
89	21 ,, ,, .	25	47	38	29	10	9	2	0	0	0	0	0	0	0	0	0	0	0	6·77	
119	20 Jan. 1941 .	15	19	23	11	6	3	1	2	0	0	0	0	0	0	0	0	0	0	6·91	From 80 metres. Crop harvested

TABLE IV

Rabi *crop 1940-41*

(Sown on 24 September 1940)

The mean values of plant attributes and their sampling error

Days after sowing	Date	Number of shoots		Number of plants		Number of leaves		Height in cm.		Number of ears		Shoot to plant ratio	Remarks
		Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.		
30	23 Oct. 1940	13·53	0·855	...	...	...	...	...	...	...	...	...	
35	28 ,, ,, .	14·17	0·754	6·98	0·367	3·66	0·073	17·71	0·603	...	...	2·030	Maximum tillering ; infested with pyrilla
43	5 Nov. ,, .	12·75	0·705	7·34	0·384	3·63	0·096	28·05	1·145	...	...	1·733	Growth in height has commenced
53	15 ,, ,, .	9·83	0·617	...	...	3·94	0·128	45·94	2·444	...	...	...	
60	22 ,, ,, .	10·41	0·655	6·43	0·349	4·72	0·151	62·67	2·900	...	...	1·619	
72	4 Dec. ,, .	8·36	0·592	5·76	0·324	6·39	0·181	110·58	4·213	1·98	0·195	1·451	Ears emerging
80	12 ,, ,, .	6·90	0·433	5·23	0·275	6·21	0·169	125·32	4·534	3·58	0·263	1·319	Bottom leaves drying off
89	21 ,, ,, .	6·77	0·377	5·20	0·265	6·01	0·141	134·79	3·713	4·93	0·286	1·302	
119	20 Jan. 1941	6·91	0·617	...	...	...	...	...	...	6·12	0·529	...	Crop was harvested. Values of two plots (N. W. and S. W. only

S. E. = Sampling error of the mean

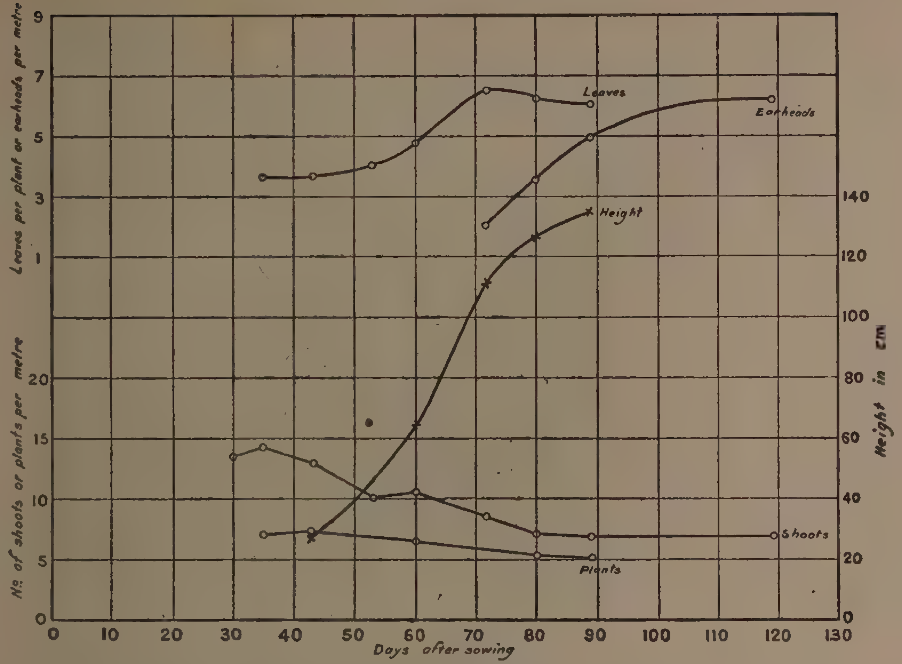


FIG. 2. Plant attributes for the *rabi jowar* 1940-41

when the crop is 89 days old. This indicates that the percentage of shoots dying out is greater than that of the plants.

Leaf. The number of green leaves goes on increasing and attains a maximum value of 6·4 about 72 days after sowing. There is a gradual fall in the leaf number later on as the lower leaves begin to turn yellow. The sampling error of the mean increases with the increase in leaf number and later decreases as the number of leaves falls down.

Height. It is interesting to note from Fig. 2 that the height curve is S-shaped and the rapid growth in height starts soon after maximum tillering is reached, and practically ceases with ear emergence. This rapid growth occurs between the 8th and the 11th week from sowing. The maximum height attained is 134·79 cm. when the crop is 89 days old. The sampling error of the mean increases and is high during the grand period of growth but comes down subsequently when all the plants attain their maximum heights and the crop becomes more uniform.

Earheads. Earheads were found to emerge 68 days after sowing; before harvest the mean number of earheads per metre was 6·12. The sampling error of the mean increases with the increase in the number of earheads. It may be noted that the mean number of shoots and ears per metre are of the same order, suggesting that most of the shoots put forth ears. Actually nearly 88·6 per cent of the shoots in the field did so.

Covariance between shoots and tillers. We noticed in Table III a large variability in the number of shoots per metre. To find out whether there is any relation between the plant number (X) and the number of tillers (Y) (shoots minus plant number) per metre the covariation between them has been worked out. Table V gives the analysis of covariance of plants to tillers.

TABLE V

Analysis of covariance of plants to tillers

Due to	D. F.	S. P. (XY)	Covariance	S (X2)	S (Y2)	$\gamma=\frac{S(xy)}{\sqrt{S(x^2)\,S(y^2)}}$
Plots	3	—24·1	—8·03	49·1	15·5	...
Between samples	76	1557·4	20·50	1635·8	2166·0	0·8273*
Within samples	80	790·5	9·88	849·0	1533·5	0·6928*
Total	159	2323·8	14·62	2533·9	3715·0	

D. F.=Degrees of freedom S. P.=Sum of products

*Significant at 1 per cent level

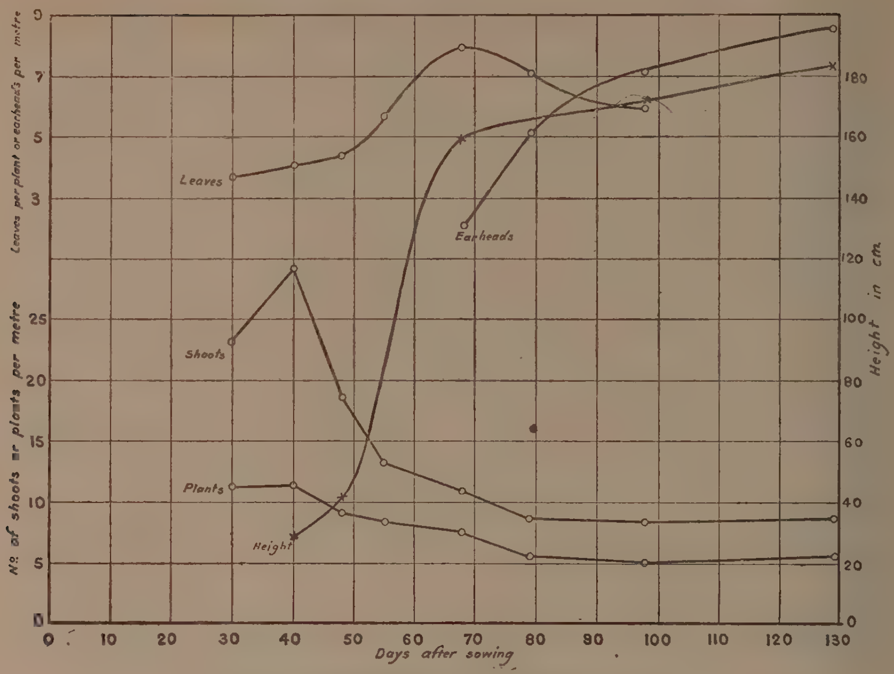


Fig. 3. Plant attributes for the *rabi jowar* 1941-42

It was found that the correlation is highly positive showing that a greater number of plants gives rise to a greater number of tillers. The capacity for tillering does not therefore seem to have been affected sensibly by the density of the population within the range of plant population occurring in the field.

Rabi *crop, 1941-42.* Table VI gives the mean values of different plant attributes and their sampling errors for the crop of 1941-42. These values are shown graphically in Fig. 3.

Plants. This year also the same seed rate as in the previous year was employed and the maximum mean number of plants per metre was 11·36, 40 days after sowing as compared with the previous year's corresponding figure of 7·34 plants per metre, 43 days after sowing. This definitely shows that the population was more in the *rabi* crop of the year 1941-42 and 16·2 per cent of the seeds sown had survived to this date. There is a gradual fall in the plant numbers and before harvest it has come down to 5·6, a decrease of nearly 50 per cent. The sampling error of the mean number of plants steadily decreases with the decrease in plant number except on 4 November 1941.

Shoots. The above tendency holds good for shoot number also. These are in accordance with the previous year's observations excepting that the mean values on corresponding dates are higher and the percentage of sampling errors calculated from the sampling errors are lower. The reason for this is that the field in which precision observations were taken in 1941-42 was more fertile and homogeneous than that in the previous year.*

The shoot to plant ratio of the 1941-42 crop reaches a maximum value of 2·55 as against 2·03 in 1940-41. This is followed by a fall. The ratio comes down to 1·56, 55 days after sowing and this is kept up till harvest. Thus the better fertility of the field is reflected also in the larger number of tillers in 1941-42.

Leaves. The mean number of leaves per shoot increases steadily until a maximum value of 7 94 leaves per shoot is reached, 68 days after sowing. In the previous year the maximum number of green leaves was 6·39. This also may be due to the better quality of the field in 1941-42. Later

* The weather conditions during the period of vegetative growth of the two *rabi* crops (1940-41 and 1941-42) were critically examined. For all practical purposes they were found to be more or less similar. The field in which the second year's crop was grown is more fertile, homogeneous and deeper than the previous year's field. The climatic conditions became dissimilar during the blooming period. This will be discussed in a later section.

Table VI

Rabi *crop 1941-42*

(Sown on 18 September 1941)

The mean values of plant attributes and their sampling error

Days after sowing	Date	Number of shoots		Number of plants		Number of leaves		Height in cm.		Number of ears		Shoot to plant ratio	Remarks
		Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.	Mean per metre	S. E.		
30	17 Oct. 1941.	23·01	1·374	11·22	0·515	3·68	0·071	...	...	...	...	2·06	
40	27 " " .	29·11	1·513	11·36	0·554	4·06	0·084	28·2	1·304	...	...	2·55	Maximum tillering. Pyrilla observed in large numbers
48	4 Nov. " .	16·16	1·371	9·24	0·708	4·34	0·118	40·3	2·255	...	...	1·75	Rapid growth commences
55	11 " " .	13·09	0·943	8·44	0·541	5·64	0·123	87·5	3·850	...	...	1·56	
68	24 " " .	10·79	0·815	7·45	0·463	7·94	0·193	158·5	5·633	2·04	0·241	1·45	Ear emergence
79	5 Dec. " .	8·51	0·631	5·66	0·372	7·07	0·203	163·8	5·987	5·11	0·432	1·50	Lower leaves drying off
98	24 " " .	8·20	0·558	5·05	0·287	5·93	0·173	169·4	4·573	7·10	0·787	1·62	Observations were taken only on Northern plot
129	24 Jan. 1942.	8·79	0·573	5·66	0·317	...	...	182·2	6·520	8·51	0·588	1·55	Crop harvested. Practically all leaves have dried up

S. E. = Sampling error of the mean

it comes down to nearly 6, 98 days after sowing. The sampling error increases with increase in leaf number and shows a fall on the last day of observation.

Height. The mean height of shoots was low till the crop was seven weeks old. Then the grand period of growth commenced and lasted for slightly more than two weeks. The maximum height attained was 182·2 cm. on the day of harvest as against 134·79 cm. in the previous year so that the figures for height also indicate that the field in 1941-42 was more fertile.

The sampling error increases as the crop increases in height but the increase is more during the grand period. A comparison of the growth in height of the two *rabi* crops reveals that in 1941-42 the grand period of growth commenced nearly a week earlier than in the previous year.

Earheads. With the end of the grand period of growth, when the crop was 64 days old, earheads were observed to emerge and the number went on increasing till a maximum number of 8·51 was reached on the day of harvest. The sampling error increased with increase in the number of earheads per metre and as many as 96·8 per cent of the shoots had put forth ears before harvest as compared to 88·6 per cent in the previous year. The mean number of ears per metre was higher while the sampling errors were lower than in the previous year.

From a comparative study of the results of 1940-41 and 1941-42 *rabi* seasons the following general inferences may be drawn :

(1) The *rabi jowar* crop of 1941-42 produced more shoots, plants and ears per metre and leaves per shoot as well as a greater shoot to plant ratio and was also taller than the previous year's crop.

(2) The percentage sampling errors for all these characters were lower for the crop of 1941-42.

(3) The grand period of growth was shorter and earlier for *rabi jowar* crop of 1941-42 and was better defined.

As has already been explained all these findings go to confirm the view expressed above that the soil was better and more homogeneous in the year 1941-42.

From the precision study of *kharif jowar* for a season and *rabi jowar* for the two seasons we find that the life-history of the *jowar* crop can be divided into the following distinct phases :

(*a*) Germination, (*b*) tillering, (*c*) elongation, and (*d*) reproduction.

(*a*) The period of germination extends over about 12 days as seen in the case of *kharif jowar*.

(*b*) The period of tillering begins soon after germination is complete and lasts from 24 days to about 40 days after sowing.

(*c*) After tillering has reached the maximum value, the crop enters the period of rapid elongation, also known as ' the grand period of growth '.

During the period lasting from about 45 days to about 70 days after sowing the crop grows in height very rapidly.

(*d*) Vegetative growth is almost over by the end of the grand period of growth and then begins the reproductive phase. This is marked by the emergence of earheads and with the conclusion of this period resulting in the formation of grain, the life-history of the crop is brought to a close. This period lasts from about 70 days to 125 days after sowing when the crop is harvested.

TABLE VII

Heights from sampling and photography

Days after sowing	Date	Height in cm. by Sampling	Height in cm. by Photography	Difference in cm.
35 . .	28 Oct. 1940	17·7	20·0	2·3
43 . .	5 Nov. ,,	28·1	30·0	1·9
53 . .	15 ,, ,,	45·9	45·0	0·9
60 . .	22 ,, ,,	62·7	60·0	2·7
72 . .	4 Dec. ,,	110·6	112·0	1·4
80 . .	12 ,, ,,	125·3	125·0	0·3
89 . .	21 ,, ,,	134·8	135·0	0·2

Photographic estimation of height

In the year 1940-41 an attempt was made to study the height of the *rabi* crop photographically. A long pole graduated into 15 cm. lengths, painted black and white alternatively, was placed vertically inside the field. From a fixed distance photographs of the crop with the graduated pole inside were taken on different days and the mean height of the crop on the different days was estimated fron the negative. Plate XVII shows a print of th photograph taken on 22 November 1940 an Table VII gives the values of height estimate by sampling along with those obtained from th photographs. It is seen that the mean height of plants as estimated photographically compar very satisfactorily with those estimated b sampling all the differences except the first bein within the limits of the 5 per cent values of thei sampling errors.

HARVESTING EXPERIMENTS

Estimation of yield by sampling. Table VIII and IX give the estimated and actual yield of grain and total weight of straw and grai together with the percentage error in estimatio and the percentage sampling error of the mean fo the year 1940-41 and 1941-42 respectively. It i interesting to see that most of the percentag errors in estimation are lower than the percentag sampling errors, indicating that because of th high variability of the crop in grain yields, th errors of estimation are not significant. Perhaps higher percentage of such a highly variable cro should be sampled so as to get more accurat estimates of the total yield. Two reasons for thi high variability in the yield are (*i*) the crop is tall one with uneven plant population and (*ii* the soil is rather heterogeneous.

From Tables VIII and IX it appears that esti mates of grain yields alone are not good for both the years as compared to the estimates of tota weight which are highly satisfactory giving ver low percentage of error in estimation. Thi suggests that the setting of grain was not uniform There was not much difference in the results ob tained by the linear and the parallel methods.

TABLE VIII

Estimated and actual plot yields of grain and total plant weight, percentage sampling error and error in estimation for rabi *jowar, 1940-41*

Particulars	Estimated plot yields: By linear method: Grains: In lb.	Per cent E. E.	Per cent S. E.	Total plant: In lb.	Per cent E. E.	Per cent S. E.	By parallel method: Grains: In lb.	Per cent E. E.	Per cent S. E.	Total plant: In lb.	Per cent E. E.	Per cent S. E.	Actual plot yields: Grains in lb.	Total plants in lb.	Remarks
N. W. Plot	96·51	12·54	13·076	840·2	—2·86	11·284	106·48	24·17	12·902	915·5	5·78	10·439	85·75	865·0	Less fertile plot
S. W. Plot	115·55	10·63	13·076	830·5	3·88	11·284	105·66	1·16	12·902	776·0	—2·94	10·439	104·45	799·5	
Total .	212·06	11·49	9·246	1670·7	0·004	7·979	212·14	11·53	9·123	1691·5	0·016	7·381	190·20	1664·5	

$$\text{Per cent E. E.} = \text{Percentage error in estimation} = \frac{\text{Estimated yield—Actual yield}}{\text{Actual yield}} \times 100$$

Per cent S. E. = Percentage sampling error

Table IX

Estimated and actual plot yields of grain and total plant weight, percentage sampling error and error in estimation for rabi jowar, *1941-42*

Particulars	Estimated plot yields: By linear method: Grains: In lb.	Per cent E. E.	Per cent S. E.	Total plant: In lb.	Per cent E. E.	Per cent S. E.	By parallel method: Grains: In lb.	Per cent E. E.	Per cent S. E.	Total plant: In lb.	Per cent E. E.	Per cent S. E.	Actual plot yields: Grains in lb.	Total plants in lb.	Remarks
Northern plot	70·35	13·47	30·440	1083	5·09	9·469	64·18	3·51	21·402	1040	0·94	8·869	62·00	1031	
Southern plot	20·40	—32·51	30·440	1266	—8·79	9·469	17·40	—42·48	21·402	1241	—10·62	8·869	30·25	1388	Better field
Total .	90·75	—1·63	21·524	2349	—2·89	6·696	81·58	—11·57	15·134	2281	—5·69	6·272	92·25	2419	

Per cent E. E. = Percentage error in estimation = $\frac{\text{Estimated yield — Actual yield}}{\text{Actual yield}} \times 100$

Per cent S. E. = Percentage sampling error

Table X

Analysis of variance, mean weight per metre, S. E. and C. V. for both the years rabi jowar

Factors	Degrees of freedom	For *rabi jowar* 1940-41: Grain weight in gm.: Linear	Parallel	Total plant weight in oz.: Linear	Parallel	For *rabi jowar* 1941-42: Grain weight in gm.: Linear	Parallel	Total plant weight in oz.: Linear	Parallel	Remarks
Plots . .	1	2142·5	4·05	0·7	138·1	14761·4	12949·0	245·9	295·5	Plot variance, rather high for 1941-42 *rabi jowar*
Between samples	38	** 2529·4	** 2219·8	** 130·5	* 114·8	** 2256·4	* 901·8	** 181·7	* 150·3	
Within samples	40	935·9	1015·1	46·8	60·4	626·0	541·6	76·0	91·1	
Total .	79	1717·7	1581·7	86·5	87·6	1589·2	871·9	129·0	122·2	
Mean and the S. E. of mean		57·65 ±5·62	57·67 ±5·27	16·01 ±1·28	16·23 ±1·20	24·67 ±5·31	22·19 ±3·36	22·5 ±1·51	21·9 ±1·37	
C. V. per cent .		87·2	81·6	71·37	66·02	192·52	135·36	59·89	56·09	

S. E. = The sampling error of the mean
C. V. = The coefficient of variation per metre
* = Significant at 5 per cent level
** = Significant at 1 per cent level

Table X, giving the analysis of variance for both the years, indicates that the total variance and sampling error by parallel method is lower than by linear method especially for grain weight. This inference is well brought out by the coefficient of variation. The mean values of grain and total plant obtained by the two methods of sampling are of the same order of magnitude so far as the totals of the two plots are concerned. These two methods were tried just before harvest to estimate the growth of the crop and the analysis of variance is given in Table XI. The parallel method is better than the linear method for all plant attributes except height. Neither of the two methods tried is quite satisfactory for estimating the height since the correlation between the two ultimate units of the same sample has not been removed by taking the units parallel instead of in a line.§ This point requires further examination.

It is to be noted that the crop of 1940-41 has yielded a larger amount of grain than the crop of 1941-42 in spite of much better growth and greater number of ears and also higher total weight in the latter year. The reason for this is to be found in the meteorological conditions prevailing during the grain-setting period. This aspect is examined in detail and will be discussed later.

§A three-tined country drill had been used in sowing so that the positive correlation for the parallel method also is perhaps understandable, as there is a higher probability of the two neighbouring metre lengths having been sown simultaneously than at different times during the movement of the drill along the rows.

Estimation from plant attributes. It is believed that the plant attributes quantitatively measured should be able to provide an estimate of the yield of crop. The growth of plants like *jowar* with a straight and non-branching stem can be morphologically studied by measuring the girth and height of the plant as well as the leaf area. An attempt was made to find out how far the girth and height measurements made 15 days before harvest are correlated with the yield of straw and grain. The method followed has already been described under 'Materials and methods.'

TABLE XI

Analysis of variance by linear and parallel method on the days of harvest

Date			20 January 1941				24 January 1942							
Plant character			No. of shoots		No. of ears		No. of shoots		No. of plants		Height in cm.		No. of ears	
Factor	Sample shape	D. F.	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel	Linear	Parallel
Plots		1	532·5	163·7	12·8	96·8	7·8	37·8	0·3	0·8	12,214·1	10,351·2	17·1	28·4
Between samples		38	30·5*	23·6	22·5*	16·9	26·3*	26·3	8·0	4·2	3,400·9**	2,767·4**	27·6	20·3
Within samples		40	14·8	17·6	8·5	12·6	15·2	26·6	5·1	4·7	654·7	817·3	16·4	24·3
Total		79	28·9	22·3	15·3	15·7	20·6	26·6	6·4	4·4	2,122·0	1,876·0	21·8	22·4
Mean value and the S. E. of the mean			6·91± 0·617	7·17± 0·543	6·13± 0·529	6·20± 0·459	8·79± 0·570	9·29± 0·570	5·66± 0·317	5·50± 0·299	182·2± 4·61	181·5± 4·16	8·51± 0·588	8·73± 0·504
Coefficient of variation (per cent)			80·0	67·7	77·1	66·3	58·4	55·2	50·0	37·3	32·0	29·0	61·8	51·7

* = Significant at 5 per cent level
** = Significant at 1 per cent level

Total yield (grain+straw)

The correlation coefficients between the different factors are given in Table XII together with their standard errors.

TABLE XII

Coefficient of correlation between height, girth, total plant weight and weight of grain

Factors	Correlation coefficient	Standard error of $\gamma=\frac{1-\gamma^2}{\sqrt{n-2}}$
1 Height and girth	+0·9286§	±0·0357
2 Height and weight of plant	+0·8522§	±0·0503
3 Height and weight of grain	+0·7728§	±0·0511
4 Girth and weight of plant	+0·9113§	±0·0396
5 Girth and weight of grain	+0·8357§	±0·0528
6 Weight of plant and weight of grain	+0·8236§	±0·0546

§Significant at 1 per cent level

The normal equations treating yield as an independent variate were solved by the method indicated by Snedecor [1938].

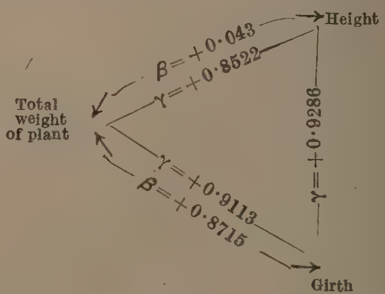
The β values are

$\beta y_{1\cdot 2} = +0\cdot 0436$

$\beta y_{2\cdot 1} = +0\cdot 8715$

where y stands for total weight of plant, 1 for height and 2 for girth.

The following is the schematic representation of the Υ's and β's.



The multiple correlation R between plant weight, girth and height is found to be as high as 0·9117 and is highly significant. The value of the multiple correlation is of the same order as the correlation between girth and total weight (0·9113) indicating thereby that by taking

into consideration the height factor we obtain no additional information.

All the correlations between the four factors shown in Table XII are highly significant. So the factors are inter-related with each other to a great extent.

Yield of grain. The β values for grain weight are

$$\beta_{1y\cdot23} = -0\cdot0394 \pm 0\cdot1383$$
$$\beta_{2y\cdot13} = +0\cdot5376 \pm 0\cdot1757$$
and $$\beta_{3y\cdot12} = +0\cdot3673 \pm 0\cdot1246$$

where 1, 2, 3 and y stand for height, girth, total weight and weight of grain respectively. Regression coefficient's t values are 0·2840, 3·0596 and 2·9474. The first β value is not significant while those for girth and total weight shows high significance when tested by t value. Of these two, girth is more important than total weight.

The value of R the multiple correlation works out to be 0·8493 and is significant at 1 per cent level. The equation relating yield to other factors is as follows :

$$\Upsilon = -17\cdot6087 - 0\cdot001143x_1 + 00\cdot7872x_2 + 0\cdot0003626x_3.$$

where Υ is weight of grains in gm., x_1 and x_2 are height and girth respectively in cm. and x_3 is the total weight in oz.

The possible sources of error in this experiment are the following:

(1) Errors in measurements,

(2) Cutting of plants at different heights above the ground,

(3) Loss of some leaves,

(4) All the plants might not have dried to the same extent before weighing,

(5) Some ears are barren and grain might have been lost during harvesting or threshing, and

(6) errors in random selection.

In spite of these possibilities, a study of the correlations between yield of grain, height, girth and total weight has given very satisfactory results indicating the possibility of predicting the yield of grain from girth measurement made about a month before harvest, provided the setting is normal. The shrinkage in grain weight expressed as a percentage of the weight of grains at harvest from these selected plants was found to be 20·25.

(c) *Estimation of the yield of total weight by plant attributes obtained from samples.* The correlations between height, number of shoots and weight of shoots per sample by linear and parallel method of sampling were found to be the following :

Correlation coefficient r	Linear method	Parallel method
r_{12}	+0·1503	—0·1940
r_{13}	+0·6000	+0·5534
r_{23}	+0·6408	+0·3453

where 1, 2 and 3 stands for mean height, number of shoots and total weight of samples respectively.

The value of r_{12} is low and not significant in both the cases thus suggesting that height is independent of the number of shoots per sample. Greater height as also higher number of shoots per sample have given rise to greater weight of the sample.

The regression coefficients and multiple correlation are as follows :

	Linear	Parallel
$\beta_{13\cdot2}$	0·5153	0·6447
$\beta_{23\cdot1}$	0·5633	0·3700
R	0·8186	0·6961

We find that both the factors, height and number of shoots contribute fairly equally to the estimation of total plant weight by linear method while mean height per sample appears to exert greater influence on the total plant weight by parallel method. The multiple correlation coefficient R is highly significant ; a better estimate of R is obtained by the linear method.

YIELDS OF 1940-41 AND 1941-42

In spite of the much more luxuriant vegetative development in the year 1941-42, the yield of grain was poorer than in 1940-41. The reason for this became obvious on a closer examination of the ear-heads. It was found that some ear heads were full of grains while others had no grains at all. In between these two types there were ear heads with various degrees of grain setting. Thus the very poor yield of grain in 1941-42 was clearly due to the partial failure of pollination and fertilization. The weather conditions associated with this partial failure of grain formation are briefly described below. The flowers open mostly between 12 midnight and 4 in the morning. So evidently the weather at night may be expected to play an important part in pollination and fertilization. The wind velocity, air temperature and vapour pressure at the epoch of minimum temperature were examined in this connection.

Tables XIII and XIV show in sequence the percentage of total ear number that were out of leaf sheath between the respective dates in each plot as well as in both the plots, together with the mean maximum and minimum temperatures, wind velocity and vapour pressure at minimum temprature epoch for the years 1940-41 and 1941-42 respectively.

As we have data only for a couple of years it is possible to make only a qualitative comparison of the main features revealed by Tables XIII and XIV.

TABLE XIII

Meteorological elements and percentage ear emergence for rabi *crop of 1940-41*

Particulars	Percentage of ear emergence			Actual yield of grains in lb.
	Between 25-11-40 and 12-12-40	Between 13-12-40 and 21-12-40	Between 22-12-40 and 20-1-41	
N. W. Plot	63·0	6·5	30·5	85·75
S. W. Plot	60·7	18·5	20·8	104·45
Total	62·0	11·8	26·2	190·20
Mean maximum temperature in °C.	30·1	28·0	27·8	..
Mean minimum temperature in °C.	16·4	11·9	10·1	..
Mean daily wind velocity in miles per hour	3·1	4·0	1·9	..
Mean vapour pressure at minimum temperature epoch	12·8	9·1	7·7	..

TABLE XIV

Meteorological elements and percentage of ear emergence for rabi *crop of 1941-1942*

Particulars	Percentage of ear emergence			Actual yield of grain, in lb.	Remarks
	Between 17-11-41 and 5-12-41	Between 6-12-41 and 24-12-41	Between 6-12-41 and 24-1-42		
N. Plot	55·5	22·1	44·5	62·00	Due to lodging on 24-12-41 only N. Plot was sampled
S. Plot	63·8	..	36·2	30·25	
Total	59·4	..	40·1	92·25	
Mean maximum temperature in °C.	30·8	31·8	30·1	..	
Mean minimum temperature in °C.	12·1	18·5	13·9	..	
Mean daily wind velocity in miles per hour	2·1	1·9	2·2	..	
Mean vapour pressure at minimum temperature epoch	8·5	9·8	8·3	..	

It will be seen from the above tables that about 60 per cent of the ears emerged during the first period, viz. 25 November 1940 to 12 December 1940 in the first year and 17 November 1941 to 5 December 1941 in the second year. The maximum temperatures are more or less similar. The main differences lie in the minimum temperatures and mean wind velocity during the first period (period of maximum ear emergence). In the second year the minimum temperatures are much lower than those in the previous year, the difference being of the order of 4·3°C. during the critical period (maximum ear emergence). At the same time the wind velocity is also smaller in the second year. It may be pointed out that a suitable temperature is necessary for opening of the flowers and sufficient agitation by wind is of great importance for effecting pollination. These conditions appear to have been more favourable in the first year. It is also significant that in the second year the air was much drier during the critical period than in the first year. This might have also influenced adversely the viability of the pollen grains. The daily values of the minimum temperatures, wind velocity and vapour pressure during the two years are plotted in Fig. 4.

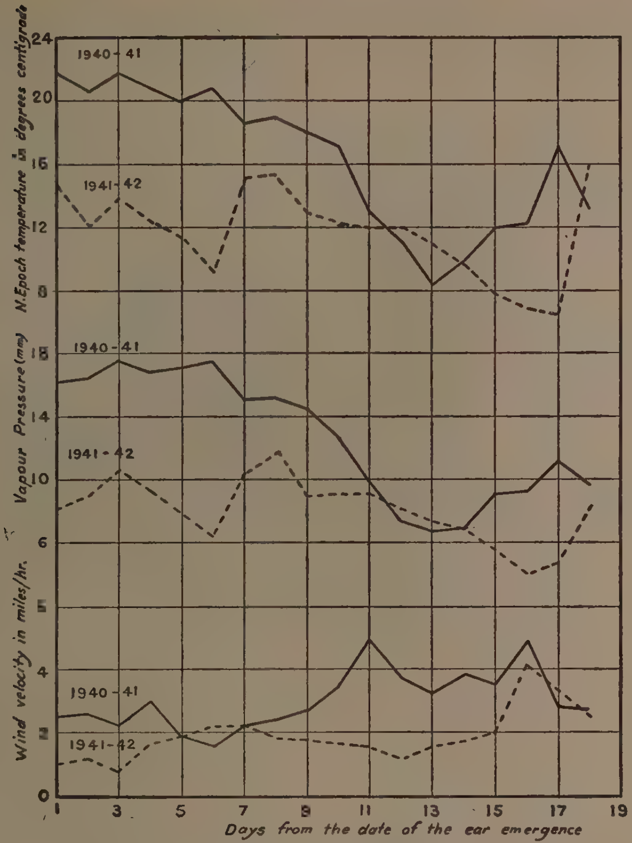


FIG. 4. Variation of minimum temperature, vapour pressure and wind velocity during 18 days after emergence of ears in *rabi jowar*

CONCLUSION

Two shapes of 2 metre sample designated as linear and parallel have been tried. During the course of analysis it is seen that in the parallel method the correlation between the ultimate units of the sample has been reduced generally, showing that this method is the better. For further improvement the following two shapes of the sampling unit where the ultimate units have been separated more widely from each other will be tried in the near future.

(1) *Linear method*. The individual metres of the sample to be separated by one metre instead of half a metre. The sampling rod will be as shown below:

Count	Omit	Count
1 metre	1 metre	1 metre

(2) *Parallel method*. Instead of taking the ultimate units from two adjacent rows, these may be taken from rows further away from each other. In the crop studied a 3-tined drill was used for sowing. Therefore for this particular case the individual metres may be so distributed that both the metres are not taken from rows sown at the same time. Thus the shape of the sample will be as shown below:

Sown together { ....1 metre / .... / .... } under observation
Sown together { ....1 metre / .... / .... }

We found that the meteorological factors such as wind velocity, minimum temperature and vapour pressure exert a profound influence on the setting of the grains. In spite of good growth, the yield of grain may be much reduced if during the period of setting the climatic factors are quite adverse. The optimum values of temperature, wind velocity, etc. during blooming period have to be determined to throw further light on this aspect of the

problem. When the data are collected for a sufficiently large series of years, it will be possible to establish crop weather relationships precisely.

ACKNOWLEDGEMENTS

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PROBLEMS OF SUGARCANE PHYSIOLOGY IN THE DECCAN CANAL TRACT

V. WATER REQUIREMENT

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(With Plate XVIII and five text-figures)

General

The problem

The Deccan Canal tract is characterized by a very precarious rainfall which causes occasional severe famines ; but due to the favourable geographical position of a range of mountains bordering on its western frontier, where rainfall is not only excessive but assured—ranging from 100 to 200 in.—Government naturally turned its attention to making some of this water available for irrigation ; and the first of a series of perennial canals—the Mutha Canal—was built in 1880, while the last—Nira Right Bank Canal—was completed in 1929. It became, however, soon apparent that as a result of the availability of water at his command for which he is assessed not by the amount used but by the area irrigated, the cultivator is apt to over-irrigate the crop. Not only has this led to a great waste of water which is brought to his door at such a high cost, but it has in addition resulted in the damage to the soil, the more obvious of which is water-logging with concomitant salt efflorescence. In this way during the last 40 years, about 35 per cent of the irrigable area of the older canals has been made unfit for cultivation and requires reclamation. Further, heavy watering brings in its trail the necessity of high manuring, which increases the cost of production, and while this tract is well known to be one of the finest sugarcane-producing tracts in the world, and with an assured supply of water, prolific crops of thick soft canes are in fact produced, the cost of production per ton of cane is found to be much higher than that of the rain-fed tracts of northern India. As, however, no systematic scientific data were available on these problems which arose with the introduction of perennial irrigation, the Bombay Department of Agriculture established a research station at Manjri in 1893 and after a great deal of field experimental work for a number of years evolved the well-known Manjri standard method (Leaflet No. 17 of 1929). It has been estimated that the improvements as recommended by this method consisting of deep ploughing by gallows plough, planting in furrows 4 to 5 ft. apart and interculturing has resulted in the saving of water by 33 per cent in the hot season and 25 per cent on the whole. Further attempts to determine the exact water requirement of sugarcane and its periodical distribution under field conditions have been rather inconclusive, and it was felt that a thorough investigation was required on the influence of the various factors operating during the life-cycle of the plant in order to elucidate this problem which is a very important one from the standpoint of the canal irrigation. This has been started with the establishment of the Sugarcane Research Scheme, Padegaon, financed jointly by the Imperial Council of Agricultural Research and the Government of Bombay and the following investigation forms the first of a series of articles in this connection.

Historical

Investigations on the exact water requirement of plants have been mainly directed to determine the ratio between the amount of water expended and the dry substance formed by the plant. The first investigation in this line has been conducted by Hellriegel [1883] who inferred a similarity in the water requirement in all the crops. This has been, however, disproved by later workers as Schroder [1895], Leather [1909, 1911], Briggs and Shantz [1914, 1917], Shantz and Piemeisal [1927], Tulaikov [1929] and Singh and Singh [1936] who found that while the crops could be divided into groups as regards their water requirement, a distinct variation among these groups could be detected. Even in cereals, Schroder [1895] distinguished two groups, the water requirement of the first group being 2·2 times that of the second. In general, the most economical plants are those of

* This scheme is partly subsidized by the Imperial Council of Agricultural Rerearch

short growing period. In the case of sugarcane, Leather [1911] has calculated the water requirement per acre to vary from 33 in. to 66 in. for the minimum and maximum production of dry weight production, while investigations by Singh and his co-workers [1935] have shown its minimum water requirement to be 45 in.

Besides the peculiarities of the plant, environmental factors—particularly meteorological conditions, soil moisture and soil fertility are found to influence the efficiency of transpiration to a great extent. An excellent historical review of the influence of these factors has been taken by Miller [1931]. Among the atmospheric factors, humidity is considered to be undoubtedly the most pre-eminent, there being great reduction in transpiration with the rise in the air humidity. The rate of transpiration increases with the rise in the water content of the soil up to a certain limit which appears to be about 70 to 80 per cent of the soil saturation. An increase above this has got no effect which is traced to the deficiency in the oxygen-supplying power of the soil. According to Singh and Singh [1936] the optimum growth of cereals may be secured at percentages between 22 to 40 while in vegetables the figure varies between 37 and 55 per cent of the water-holding capacity of the soil. Leather [1911] maintains that the concentration of water in the soil which is necessary for good development varies largely with the nature of the soil. While in Pusa soil 10 per cent moisture is sufficient for the development of good plants, in the black cotton soil 25 per cent is too small for any thing but the most meagre growth. Provided, however, the water supply does not fall below a certain concentration, the physical nature of the soil has no influence on the transpiration ratio. On the other hand, the degree of the fertility of the soil produces a considerable effect on it. It has been observed by Kiessalbach [1916] that while manuring of soil diminishes the intensity of transpiration, its effect is more strongly marked with the poor soil and only slightly with the fertile soil.

Very little information of a definite nature is available as regards the influence of the ground water level on the water requirement. Balls [1919] states that due to the proximity of water table, the cotton plant in his experiments in Egypt drew on it for a portion of its needs which resulted in the high utilization of water by the crop than what was applied in irrigation. Israelsen [1935] considers that the drainage of the Millard country land has contributed to the increase in the irrigational requirement of the crops, although it is not as great as is generally supposed. From his experience at Chakanwali in the Punjab, Taylor [1935] has suggested that in the areas with a water table of about 2 ft. below the surface, 30 per cent less water is required to mature a sugercane crop than in areas having it below 8 ft.

Factors

It would be seen from the above historical review that the important factors responsible in the transpirational loss of water are the inherent characteristics of the plant and the changes in the environment. In order to determine the influence of inherent characteristics, two varieties with divergent characteristics were included in the experimentation. POJ 2878 is an early-maturing, flowering variety, while Pundia is a very late-maturing, non-flowering one. There is also a great deal of variation in the underground behaviour of these varieties, the former being deep-rooted and the latter a shallow-rooted one. The environmental factors consist of (1) soil, (2) ground water-table, (3) meteorological conditions, (4) cultivation methods, and (5) manuring. The conditions prevailing in the experimental series are described below.

(1) *Soil*. The soil of the Deccan Canal tract falls under the broad group of *Regur* or black cotton soil. This is further classified by Basu and Sirur [1938] into distinct soil types according to the modern genetic method based on profile characteristics. According to this classification, the soil under experimentation is denominated as type 'B' and possesses the following characteristics.

This is a thoroughly leached soil, and also poor in colloid both organic and inorganic. The depth of the soil varies from $2\frac{1}{2}$ in. to 6 ft. or more and is generally underlaid with *murum* substratum. The drainage is not bad and the moisture retentive power is good. The soil is rather cloddy and as a result cultural operations are found to be beneficial in the way of proper aeration and nitrification. Farmyard manure gives a poor response in this soil but phosphatic manures have given promising results [Rege and Sannabhadti, 1943]. It is also well supplied with calcium carbonate. The moisture equivalent as obtained by Briggs and McLean method [1910] is 43·8 per cent while its wilting coefficient approaches 26·1 per cent on oven-dry basis. Some typical analytical results are given in Table I.

(2) *Ground water-table*. A number of permanent bore holes have been maintained on the farm area on the grid system in order to keep a record of fluctuations in the subsoil water level. One of these bores adjoins the land selected for water experiments and a record of weekly fluctuations in the water depth has been maintained throughout. The trend of the annual fluctuations showed that the average depth of water during the growing

eriod of cane was near about 9 ft. while the mini-um (6 to 7 ft.) was reached somewhere in October November after the monsoon. The soil depth this experimental series varied from 24 in. to 48 . with *murum* isobath. The exposure of the oot system of both the varieties had shown the aximum penetration of roots to vary between 2 3 ft. according to the depth of the soil, there eing no penetration beyond this even in the case f higher depth of soil. Special experiments laid own to determine the capillary rise through *urum* gave negative results. It would be thus uite evident that in this experimental series there as been practically no contribution from the ground water-table to the water requirement of the crop.

(3) *Meteorological conditions*. A well-equipped meteorological observatory has been set up on the farm where day-to-day observations are being maintained in order to determine their influence on the developmental behaviour of the crop. The data for a few important factors are given in Table II for the first series of experiments described in sections I and II. The climate is mainly sub-tropical with well-defined rainy and dry seasons, extreme temperatures of the year being between 36° and 45°F. as minimum occurring during the months of December and January and

TABLE I

Some analytical figures of soil type 'B' according to its profile characteristics

Depth (in.)	$CaCO_3$ per cent	*p*H	Exch. Ca. m.e. per cent	Exch. Mg. m.e. per cent	Exch. K m.e. per cent	Exch. Na m.e. per cent	Humus per cent	Total N per cent	Total P_2O_5 per cent	Total K_2O per cent
0-9	9·61	8·79	26·25	10·42	1·97	4·08	0·95	0·048	0·042	0·313
9-20	8·87	8·31	30·89	9·88	2·64	4·40	0·27	0·044	0·113	0·606
20-26	11·74	8·41	22·00	13·75	3·44	9·79	0·19	0·039	0·126	0·380
26-32	13·87	8·57	30·50	18·23	3·76	11·34	0·31	0·038	0·130	0·410
32-38	10·49	8·57	28·78	12·30	1·45	11·54	0·19	0·036	0·124	0·440
38-44	12·03	8·54	44·50	15·09	3·36	11·28	0·17	0·033	0·138	0·411

TABLE II

Monthly averages of some important meteorological factors

Month	1933					1934					1935				
	Rain-fall in inches	Temperature °F.		Humidity per cent at		Rain-fall in inches	Temperature °F.		Humidity per cent at		Rainfall in inches	Temperature °F.		Humidity per cent at	
		Max.	Min.	8 a.m.	3 p.m.		Max.	Min.	8 a.m.	3 p.m.		Max.	Min.	8 am.	3 p.m.
anuary	0·00	88·0	52·5	65·8	...	0·00	84·1	50·0	81·1	39·1	0·00	83·8	51·1	67·9	30·5
ebruary	0·00	94·3	56·4	63·5	...	0·00	97·1	51·7	66·8	22·9	0:00	91·0	51·7	59·9	14·5
larch	0·18 (2)	100·0	62·4	54·3	...	0·18 (1)	96·4	59·2	53·3	19·5	0·00	95·3	57·6	43·4	12·8
pril	0·00	101·1	69·6	45·9	18·0	0·66 (3)	103·2	69·5	57·6	19·4	0·00	98·9	66·4	52·1	15·0
lay	0·94 (5)	97·2	72·5	68·8	38·2	1·27 (2)	102·2	70·8	51·2	16·9	0·00	102·6	72·1	48·1	16·9
une	2·74 (13)	88·1	71·9	77·3	56·8	4·57 (10)	90·9	71·7	73·0	76·7	2·66 (10)	91·9	69·7	75·8	47·2
uly	2·61 (10)	84·9	71·4	81·9	67·3	1·84 (16)	89·2	70·8	85·9	75·0	0·90 (8)	84·6	71·9	75·8	57·5
ugust	3·66 (11)	83·0	69·8	87·1	73·2	1·16 (10)	83·4	70·8	83·2	66·8	6·47 (11)	84·2	70·2	84·4	63·9
eptember	4·69 (14)	85·9	68·8	85·4	70·4	2·70 (6)	84·8	68·3	81·1	56·6	1·37 (5)	84·8	67·8	83·4	53·4
ctober	1·20 (11)	88·1	65·8	83·4	44·5	4·06 (7)	88·4	65·7	75·7	38·5	6·60 (14)	87·3	67·9	82·5	51·5
ovember	1·07 (5)	86·4	61·3	74·4	34·8	5·57 (3)	82·1	52·6	82·3	45·3	0·00	85·5	53·6	79·0	30·0
ecember	0·75 (2)	82·6	71·1	69·4	36·6	0·00	82·3	48·9	75·6	40·1	0·36 (1)	84·6	52·0	77·3	31·5
Total	17·93 (69)	...	...	...	...	21·01 (58)	...	...	...	...	18·36 (49)	...	...	...	...

Figures in brackets indicate the number of rainy days

between 105° and 110°F. as maximum during April and May. The growth of the plant practically ceases when these conditions occur, but tillering is not much affected. With the onset of monsoon, there is a rapid drop in the maximum temperature which remains fairly constant at about 86°F. when the diurnal range is also at its minimum (14°F.). In the case of sugarcane, this period coincides with the grand period of growth and from the standpoint of temperatures approximates the optimum conditions. It would be further evident from the table that while the temperature fluctuations from year to year are the least during the growth period, the distribution of rainfall as well as humidity are extremely variable. Although from the standpoint of total rainfall these three seasons do not show wide variation, the records of the last 14 years have shown such wide fluctuation as 9 to 33 in. The average rainfall is about 19 in. and this is not only not sufficient but is precarious and from the standpoint of dry farming, the cultivation of even short-term crops as *jowar* or *bajri* is purely a gamble. With the introduction of canal irrigation, the importance of rainfall is minimized and crops like sugarcane are grown with security. It has been, however, found from other experimental data that in spite of controlled conditions of irrigation and manuring, other climatic factors—specially humidity—do play an important part in the plant development. An analysis of the data collected for six years has shown a correlation of growth with humidity which is found to be significant at 0·01 level for five years in the case of Pundia and for three years in the case of POJ 2878. This is also well illustrated in Fig. 1 where mean temperatures and humidity

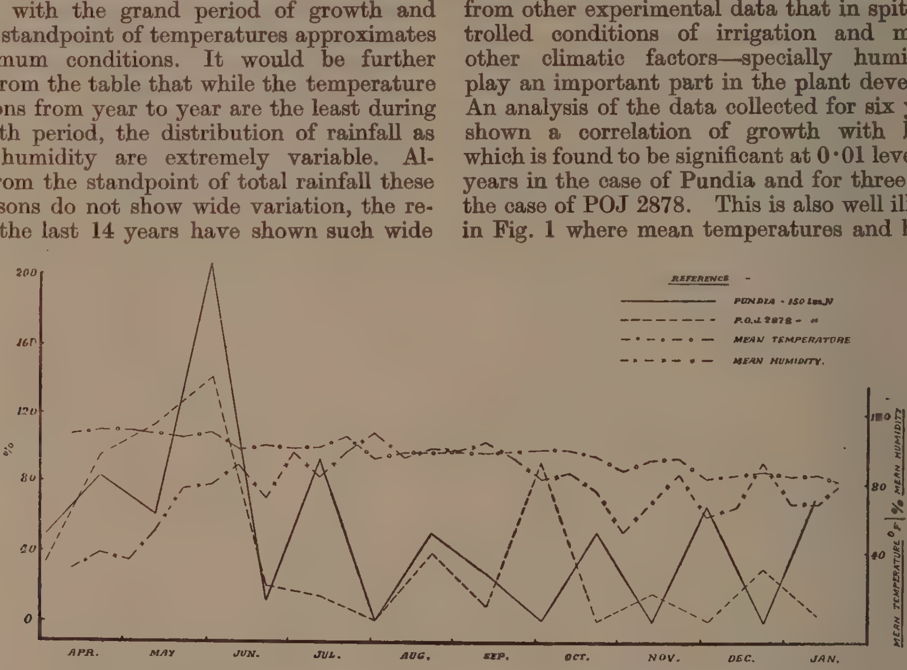
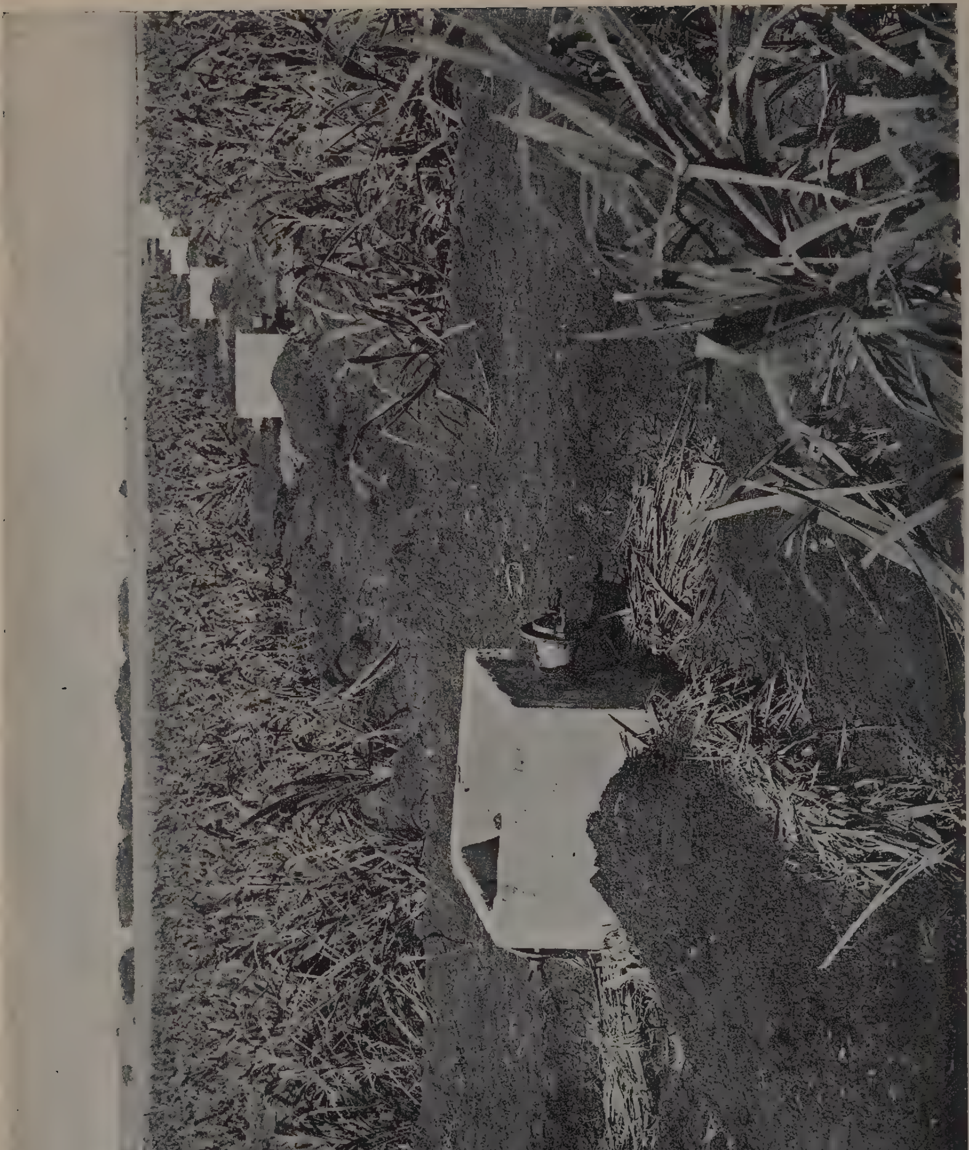


FIG. 1. Periodical increase in dry weight corrected with atmospheric factors—1933-34

are represented in relation to the increase in weight of two varieties calculated by the Blackman's formulae. It clearly brings out the varietal characteristic, Pundia being more susceptible to changes in the humidity than POJ 2878. Some of the new Coimbatore varieties as Co 419, Co 360, Co 413 have been found to be even more indifferent to climatic fluctuations than POJ 2878. The detailed analysis of the climatic relationship will be dealt with in a separate paper; but it can be definitely said in general that the humid oppressive climate precursory to rain is the ideal condition for growth of sugarcane and during those seasons such days are many, the crop yields are the best. It would be thus quite evident that besides its direct influence on the rate of transpiration, atmospheric humidity would also play an important part in determining the efficiency of water requirement of sugarcane by affecting its growth. It has been, however, observed that the deleterious effect of its deficiency under natural conditions is modified to some extent by the capacity of the crop to create its own humidity due to periodic irrigation; once the crop has attained its full tillering and sufficient height to prevent the free movement of wind which attains a high velocity in this tract. About 4 to 12 per cent higher humidity is prevalent inside the crop than outside, depending upon the size of the block, and the higher figure has been found to be more common on the developed canals where both due to growth of trees and larger area under cane, the velocity of wind is controlled to a greater extent. The absence of great variability in yields and the better performance of the susceptible varieties like Pundia and E K 28 on these developed canals would be thus quite explicable. The site for these experiments was, however, specially selected on a new canal where the environmental conditions would be more exacting, so that the results on the minimum water requirement could be recommended with assurance to any place in this tract.



Water distributing tanks showing outlets on both sides for letting out water to plots on both sides with flap arrangement for letting out water. The tanks are connected by 4 in. hume pipes underground through which the water measured by the meters flows

(4) *Cultivation methods.* These had received a very careful investigation at Manjri and the methods evolved there have been followed in toto in these experimental series. These consist of deep ploughing by Gallows plough, planting in furrows 4 ft. apart, slow irrigation, interculturing a few times till the crop makes sufficient growth and earthing up when two or three internodes are formed on the surface. The number of setts required for planting were fixed as 10,000 three-budded setts per acre.

(5) *Manuring.* Manuring of sugarcane has been found to be quite essential in this tract and consists chiefly of basal sunn green manuring or a heavy dose of farmyard manure if available and nitrogenous top-dressings of both sulphate of ammonia and oil cakes. While the standard Manjri method has recommended 150 lb. N as a suitable quantity, doses from 300 to 400 lb. N are not uncommon.

Outline of the scheme of work

The problem of the water requirement in the case of sugarcane is complicated by the fact that the crop is irrigated throughout its life-cycle at short intervals and is further heavily manured with nitrogenous top-dressings and the investigations must necessarily comprise a close study of the interrelationship of water and manure. A comprehensive programme has, therefore, been outlined to find out (1) the minimum delta to raise a normal crop with a view to spread the available canal water on the maximum acreage, (2) the suitable combination of water and manure to secure the maximum yield per acre, (3) the periodic distribution of the total delta in order to utilize it to the best advantage, and (4) the variable behaviour of the soil types.

These quantitative studies are mainly carried out in the field and differ in this respect from the standard method of pot culture. The latter method is no doubt capable of greater accuracy; but for the same reason it has to be conducted under conditions which do not approach to the field practices. It is, for instance, necessary to transfer the soil to the pots thus disturbing the profile characteristics, which according to the modern genetic conception of soil classification give a true index of the soil type. The most obvious difference is found in the root distribution specially in the heavier soil groups such as the black cotton soil. It has been observed that while in the field the root-system is restricted within a depth of about 36 in. the same soil when transferred to the pots shows its very free development throughout the depth of the soil (48 in.). As regards the method of irrigation, surface irrigation is the common feature in the field while sub-irrigation is essential in the pot-culture experiments. It has been estimated by Widstoe [1909] that surface irrigation entails about 60 per cent more loss by evaporation than in the case of sub-irrigation. In the case of soil moisture, wide fluctuations occurring in the field during the irrigational intervals are not permitted in the pot-culture series where the moisture is kept at a definite figure and the loss is made good either daily or on alternate days. It would be thus quite evident that these differences between the pot-culture and field practices would diversely influence the results and it is for this reason that the method of pot culture is not considered by us as quite suitable for securing practical recommendations as regards the irrigational quantities under field conditions. It has been, however, utilized, whenever necessary, to test the validity of some important findings accrued from the field studies about the influence of edaphic factors.

Very reliable data can be obtained by field experimentation if certain conditions are satisfied and the possible sources of error are avoided. One obvious cause of great inaccuracy in field experiment is the loss by percolation and absorption in the irrigational channels which has been found to vary from 22 to 40 per cent depending upon the distance of the field. This has been entirely prevented in these experiments by taking water straight to the experimental plots through underground cement pipes and distribution tanks fitted with quick opening outlets (Plate XVIII) the quantity of water being accurately measured by Leed's differential rotary water meters which measure water quantities to a minimum of 10 gallons. Due to the undulating topography of this tract, the plot size in the ratio of 1 : 10 as recommended for dry-farming experimentation is found to be impracticable from the standpoint of uniform distribution of irrigational water and this is therefore modified to the ratio of about 1 : 1·7, the actual size being 32 ft. × 54·45 ft. with eight rows 4 ft. apart which equals exactly four cents in area. The main experimental plot excluding the ring is 2·5 cents or 1 *guntha* and contains a population from 600 to 1000 canes. As regards the layout, a statistically replicated method of pooling together all the treatments and varieties in a complex experiment is adopted and in order to avoid the effect of adjoining treatments an additional space of 8 ft. between the individual plots is left. This was left uncropped during the first series of experiments; but as it was found to affect the growth of the crop adversely due to isolation of small plots it was cropped throughout in later series. Each series of experiments was conducted for three years in order to ascertain the effect of seasonal fluctuation. The rotation observed was also a three years' one, viz. sunn (for green manuring)—cane—*rabi jowar*. The area chosen for the layout of the experiment had graded depths varying from 2 ft. to 4 ft. from the first year block to the third year.

The first series of experiments is outlined to fix a minimum and optimum delta for the same manurial dose while in later series the inter-relationship of water and manure is investigated. Special experiments were also conducted to evaluate the different systems of irrigation and to study the effect of varying intervals and wilting on the crop growth and it is proposed to discuss all these data in a series of papers. The following sections describe only the first series of experiments dealing with the total delta.

Total delta : developmental studies

This series of experiments was designed to determine both the minimum and optimum quantity of water under the same manurial dose. As under field conditions it is essential to conduct comparative trials with some treatments below and above the delta considered to be the normal requirement of the crop, this series consisted of four water treatments, viz. 70, 95, 120 and 130 acre-inches. In fixing these, the previous investigation at Manjri has been very useful, which has suggested the normal requirement to lie somewhere near 100 in. per acre. The last treatment of 130 in. reflects the cultivator's system. A uniform 10 days irrigation turn is maintained throughout the life-cycle of the plant after the third week from planting. The manurial dose is 150 lb. N in all the treatments distributed according to the standard Manjri method. The distribution consists of 50 lb. N at three weeks after planting in the form of sulphate of ammonia alone, 50 lb. two months after planting in a mixture of sulphate of ammonia and safflower cake in equal proportions and 50 lb. at earthing in the form of cake alone. The water deltas are inclusive of total rainfall and are limited to 12 months period, additional quantity being applied later to Pundia which requires about a month more to attain its maturity. The rainfall which is an uncontrollable factor under field conditions was divided into non-effective and effective depending upon whether it was received soon after irrigation or later on. It was found that in case the irrigational quantity was sufficient to saturate the depth of soil, the rain which fell during the period of the gravitational movement of water through the soil depth, which took three days in this soil did not contribute to the soil moisture and was entirely ineffective. Further effectiveness of the rain would depend upon the loss of moisture in evo-transpiration. As a general procedure therefore any rain falling within the first five days after irrigation was added to the total delta to be received by the crop, while the rain falling later on was deducted from the water quantity of the next irrigational turn, being considered as effective. This method has been found to be conductive to crop growth specially in the higher treatments where the application of the full irrigational dose after the rainfall may have resulted in the flooding of the whole field. The layout was a simple randomized one consisting of four water treatments and two varieties with six replications.

Presentation of data

(1) *Germination*. Figures for periodical germination are given in Table III.

Table III

Germination data

(Average of all rows per replicate excluding the border rows)

Variety and treatments	1933		1934		1935	
	3 weeks	6 weeks	3 weeks	8 weeks	3 weeks	8 weeks
Pundia—						
70 in. + 150 N	8·32	32·1	6·31	40·9	6·62	61·6
95 in. + 150 N	8·04	33·6	5·03	40·3	6·75	57·7
120 in. + 150 N	8·72	32·3	8·47	41·0	6·11	58·2
130 in. + 150 N	6·79	30·8	6·44	41·0	7·06	58·4
Mean	7·97	32·2	6·56	40·8	6·66	59·0
POJ 2878—						
70 in. + 150 N	8·33	47·1	1·44	47·5	4·77	66·7
95 in. + 150 N	9·09	44·2	3·03	46·7	5·94	65·4
120 in. + 150 N	7·24	39·4	2·51	44·2	4·60	63·9
130 in. + 150 N	8·41	40·8	3·49	48·5	5·08	64·7
Mean	8·27	42·9	2·62	46·7	5·10	65·2
C. D. for significance between varieties	3·17	4·36	0·98	1·29	0·89	2·18
C. D. for significance between any two treatments	5·82	7·92	2·21	2·88	2·02	4·90

The number of setts per row was kept constant on the basis of 10,000 three-budded setts per acre and the periodical counts of germination were taken in all the plots leaving out only the two border rows per plot. Irrigation was similar in all the treatments during the first three weeks. The first dose of nitrogenous top-dressing of 50 lb. N was applied all in the form of sulphate of ammonia at three weeks with 2 in. of irrigation after which the differentiation between the water treatments followed. Planting was done by mid-January except during the first year when owing to the time taken for fitting of the irrigational pipes and tanks, it was delayed by about a month. During the first year, the land could not also receive timely ploughing due to heavy rainfall (33·3 in.) during the previous season and the construction works mentioned above; and as a result the soil had not attained the proper tilth at the time of planting. This has caused a very poor germination in the case of Pundia in all the treatments, while in the case of POJ 2878, the deleterious effect of higher watering is visible although it is not quite significant owing to high error factor. The progressive fall in germination at six weeks with increase in watering dose is quite illustrative. The low germination in all the treatments observed during the season of 1934 is mainly due to low temperatures which prevailed soon after planting. On the other hand, temperatures during 1935 were very favourable leading to the highest germination during this season. The treatment effect is not, however, visible during both the seasons. These data of three years are a good illustration of the possible effect of soil and climate on germination as described by Rege and Wagle [1939]. They also bring out clearly that POJ 2878 has a better germinative capacity than Pundia.

(2) *Tillering and borer counts*. These were taken on two random rows per plot making up a total of 12 rows per treatment. Although monthly counts of both tillers and borer attacks are maintained till the operation of earthing up, only the figures of the maximum population and maximum borer infestation with percentage success in the case of the former are given in Table IV.

The results indicate that so far as tillering is concerned there has been no significant variation due to treatments. It depends more on the initial number of germinated buds, the lesser this number the greater the tillering. In other words there is a limit to the plant population, which a specified area can hold, and the function of tillering is circumscribed by this limitation. It would be thus evident that with a better germinative capacity of POJ 2878, the ratio of tillers to mother plants are less than in the case of Pundia. So also with higher percentage of germination during the season of 1935-36, the tillering ratio has fallen in both the varieties. The number of canes at harvest and their percentage success would give an idea of the great waste of energy by the plant which is higher in the case of Pundia than in the case of POJ 2878.

In the case of the borer attack, the varietal characteristic is also prominent, POJ 2878 being definitely less susceptible to it than Pundia. There is also an indication of an increase in the borer damage from year to year. As regards the treatments, the advantage of higher watering in reducing the infestation of borer is quite evident, the data being significant against 70 in. in the case of Pundia during all the seasons.

(3) *Growth*. This has been periodically measured directly in the field by such observation as total height, height of millable cane, number of mature and immature internodes, circumference and the number of green leaves. The methods are the same as described by Rege and Wagle [1939] previously. In order to keep the table within limited dimensions a few typical data are given with their statistical significance in Table V for the last two seasons as the first season was mainly utilized in standardizing these methods of observations.

The comparison of the data for the two years clearly brings out the influence of meteorological factors (the average figures for the same for the respective periods are also given in this table) on growth and also the water requirement of the plant. The beneficial influence of humidity on growth has already been pointed out and it is this climatic factor which has been low during the season of 1935-36 till mid-August and has adversely affected the growth in spite of a good start in germination. Although climatic conditions improved later, POJ 2878 could not make up for this initial decrease in growth due to its characteristic of early flowering and as a result the plants remained throughout poor in height as compared to the previous season. On the other hand, Pundia was helped by the high temperatures of winter months of this season which has enabled it to attain practically the same height as in the previous season.

The growth data also clearly bring out the water relationship of the plant at different periods of its life-cycle. During the early phase, i.e. till mid-August, the favourable effect of higher waterings is visible specially in POJ 2878, which is more prominent during the adverse season of 1935-36. The absence of clear indications in the case of Pundia seems to be due to the neutralizing effect of the leaching of the nutrients by higher irrigation which will naturally affect more a shallow-rooted variety like this than a deep-rooted one as POJ 2878. This favourable effect of higher waterings on the height is, however, transitory and is entirely masked by the later growth. The systematic fall

TABLE IV

Plant population and percentage borer attack

(The plant population is expressed for 10 ft. length)

(Average of two random rows per replicate, i.e. 12 per treatment)

	1933-34					1934-35					1935-36				
	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 3	Per cent borer	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 8	Per cent borer	Mother plants	Total population before earthing	Canes at harvest	Per cent success on 13	Per cent borer
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pundia															
70 in.	8·3	39·4	15·7	39·8	22·1	10·8	35·4	14·96	42·3	23·1	17·1	39·1	16·8	43·7	41·2
95 in.	9·1	40·5	20·6	50·9	18·9	10·9	33·1	13·4	40·5	21·1	15·9	45·3	18·5	47·1	35·1
120 in.	9·4	44·0	21·1	48·0	14·8	10·8	34·6	12·2	35·6	19·9	16·4	45·7	17·3	42·1	22·4
130 in.	8·4	39·7	16·0	40·2	19·0	11·3	37·8	13·9	36·6	17·7	15·9	40·7	16·6	46·2	33·4
Mean	8·8	40·9	18·4	49·7	18·7	11·0	35·2	13·62	38·75	20·45	16·3	42·7	17·3	44·8	33·0
POJ 2878															
70 in.	12·2	44·2	26·0	58·9	13·7	13·1	39·1	16·8	43·0	13·1	15·5	41·4	22·2	52·1	15·1
95 in.	12·0	41·2	24·9	60·4	13·4	12·9	37·7	18·2	48·2	13·2	18·0	42·4	26·3	58·1	13·0
120 in.	10·7	44·4	24·9	56·0	12·8	12·9	39·4	18·9	48·0	13·3	18·5	42·6	24·8	53·9	12·8
130 in.	11·6	38·9	25·1	64·4	14·9	12·9	39·0	18·5	47·4	13·2	17·6	42·3	24·1	58·4	11·6
Mean	11·6	42·2	25·2	59·9	13·7	13·0	31·3	18·1	46·65	13·2	18·2	42·2	24·4	55·6	13·1
C. D. for significance between varieties	0·99	2·86	1·95	...	0·79	0·88	1·65	1·32	...	0·58	0·59	3·49	1·64	...	1·0
C. D. for significance between any two treatments	2·42	7·07	2·94	...	1·98	2·0	3·71	2·97	...	1·31	1·34	7·84	3·74	...	3·82

TABLE V

Botanical observations in relation to meteorological factors

(Average of six plants per plot, i.e. 36 plants per treatment)

Variety and treatment	Before earthing		Mid-August				Mid-October				Mid-January			
	1934	1935	1934		1935		1934		1935		1934		1935	
	Total height (in.)	Total height (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.)	Height of millable cane (in.)	Circumference (in.
Pundia														
70 in.	19·3	15·3	24·8	5·2	10·4	2·4	56·1	5·3	39·1	4·0	68·4	5·0	71·4	4·5
95 in.	18·3	16·5	25·3	5·1	21·1	3·1	51·6	5·2	45·5	4·6	73·4	4·9	74·6	4·3
120 in.	20·4	19·3	25·5	4·9	20·8	2·0	55·3	4·9	50·1	4·3	71·4	4·8	81·3	4·3
130 in.	19·9	16·4	26·9	5·0	12·9	2·5	54·5	4·9	47·4	4·7	73·5	4·7	74·9	4·2
Mean	19·5	16·9	25·6	5·1	16·3	2·5	54·4	5·1	45·5	4·4	71·7	4·9	75·6	4·3
POJ 2878														
70 in.	23·4	17·3	27·8	4·7	17·5	3·2	79·0	5·2	60·6	3·5	95·4	4·3	82·1	3·3
95 in.	23·5	18·3	29·0	4·4	17·3	2·6	77·4	4·5	52·5	3·4	94·2	4·1	87·3	3·3
120 in.	26·1	22·5	30·3	4·3	25·0	3·7	78·2	4·3	69·2	3·5	92·6	3·9	87·8	3·4
130 in.	26·4	24·3	29·7	4·4	26·6	3·8	77·5	4·1	59·6	4·0	89·1	3·8	94·1	3·5
Mean	24·9	20·6	29·2	4·5	21·6	3·3	78·0	4·5	60·5	3·6	92·8	4·0	87·8	3·4
C. D. for significance between any two treatments	3·04	3·07	3·92	0·31	7·46	1·19	9·09	0·54	7·32	0·57	6·57	0·24	12·89	0·33
C. D. for significance between any two varieties	1·55	1·49	0·71	0·06	3·62	0·22	4·66	0·10	3·59	0·28	3·20	0·12	2·01	0·17

Meteorological factors	Mid-March to end of June		End of June to Mid-August		Mid-August to Mid-October		Mid-October to Mid-January	
	1934	1935	1934	1935	1934	1935	1934	1935
Max. Temperature °F.	98·7	97·9	83·8	84·3	85·6	85·9	83·4	85·7
Min. Temperature °F.	69·8	69·3	7·08	71·3	69·1	68·1	52·5	55·5
Mean humidity per cent	43·8	40·9	80·0	68·4	67·2	68·4	58·1	57·4
Wind velocity miles per hour	7·8	7·5	6·8	8·0	6·1	5·1	1·4	1·7
Evaporation cents	47·4	51·0	18·6	27·5	23·0	24·1	18·7	19·8
Rainfall in inches	5·68	2·66	2·98	0·99	5·50	11·73	7·03	3·25

in girth in the case of Pundia with increasing doses of irrigation is a clear evidence of the higher susceptibility of this variety to the leaching down of nutrients.

Simultaneous periodic determinations of leaf area and carbon assimilation by Ganos' punch method on the topmost fully developed leaf in the field have not shown any clear differentiation between the treatments and therefore the data are not presented. In the case of carbon assimilation, the only fact worth noting is the varietal characteristic, Pundia showing a higher rate of assimilation than POJ 2878. As would be shown later, this is in consonance with the figures of tonnages in these two varieties. The influence of irrigation on the root-system is already discussed in a separate paper by Rege and Wagle [1941]. It has been shown that higher watering tends to produce a superficial root-system and a fall in root weight which is more evident in the case of Pundia.

(4) *Flowering*. Among the two varieties under experiment, POJ 2878 is the only flowering variety and the data of the periodical flowering were maintained in this variety during the later two years for two random rows per replicate. The figures for both the years showed a similar trend of early flowering with higher watering although the differences were not significant. The data are not therefore given. It was further observed that in the case of 70 in. a greater number of canes escaped flowering which seems to be the reason why eventually this treatment has made up in growth and tonnage as these non-flowered canes continued to grow when the growth in higher waterings practically came to a standstill. This has, however, affected its maturity.

(5) *Internodal lengths*. These are illustrated in Fig. 2 for the season of 1935-36 only as their presentation for all the other years was not considered necessary owing to great similarity of figures from year to year. The only fluctuation

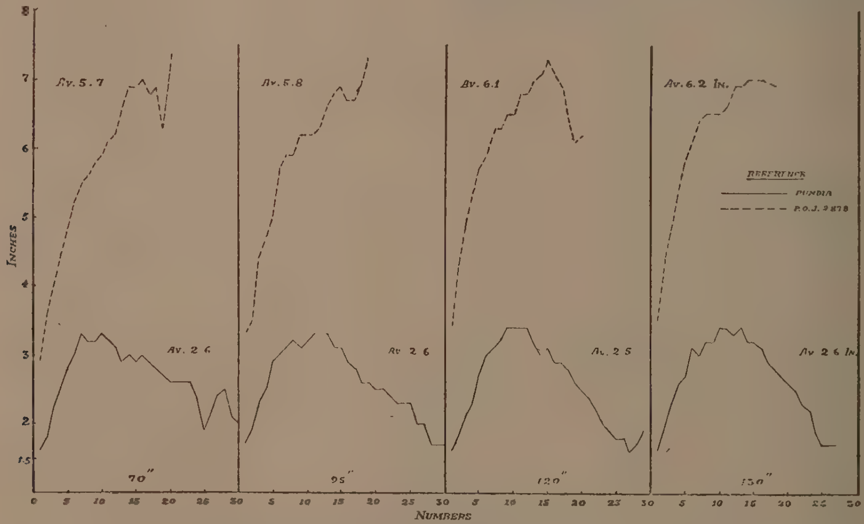


FIG. 2. Internodal lengths

observed was in the number of internodes which slightly varied from season to season. The figure clearly brings out the inherent characteristics of the two varieties, the internodal lengths as a rule being much greater in the case of POJ 2878, with the consequent fall in their number, than in Pundia. The longest internodes are, however, formed during the grand period of growth in both the varieties. Further, while in the case of POJ 2878 there has been hardly any formation of internodes after this period owing to flowering, the process continued in the case of Pundia even after this period but with the continuous fall in the length of the internodes with the progress in their number. The influence of differential waterings is clear only in POJ 2878, the average length being greater in the case of higher waterings. There are also indications of the beneficial effect of higher waterings as 120 in. and 130 in. in Pundia when one considers the formation of the longest internode. This effect seems to be, however, short-lived and the later-formed internodes get shorter in these waterings than in the lower ones perhaps due to the leaching of nutrients. This is the cause of the similarity in the average figures in the case of all the waterings.

(6) *Harvest data*. Some important data collected at the time of harvest are given in Table VI for individual years and also as an average for all the three years. During all these years

TABLE VI

Harvest data

Variety and treatment	1933						1934						1935						Average of 3 years					
	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5° C.	Purity per cent	Fibre per cent	C. C. S.—tons per acre	Weight per cane in lb.	Yield of cane in tons per acre	Brix at 17·5°C.	Purity per cent	Fibre per cent.	C. C. S.—tons per acre	Weight per cane in lb.
Pundia																								
70 in. + 150N	38·7	17·53	86·1	9·44	4·19	5·02	20·4	18·17	88·7	9·80	2·17	2·82	26·0	17·17	82·2	9·16	2·73	3·24	28·3	17·94	84·0	9·47	2·95	3·70
95 in. + ,,	40·5	17·44	86·2	9·87	4·34	4·61	19·9	17·99	84·4	10·20	2·12	3·11	30·2	17·28	86·6	9·01	3·25	3·57	30·2	17·55	85·7	9·69	3·16	3·76
120 in. + ,,	43·4	17·49	84·6	9·85	4·52	4·18	13·4	17·72	86·0	9·17	1·49	2·40	27·4	17·56	86·7	9·27	3·02	3·15	28·1	17·59	85·8	9·43	3·05	3·24
130 in. + ,,	36·8	18·13	87·1	9·11	4·04	4·36	18·5	17·65	88·0	10·89	2·05	2·96	22·9	17·60	86·3	10·35	2·47	2·84	26·1	17·99	87·1	10·12	2·86	3·39
Mean .	39·8	17·65	86·0	9·57	4·27	4·54	18·1	17·88	85·5	10·01	1·96	2·82	26·6	17·39	85·4	9·45	2·87	3·20	28·2	17·77	85·7	9·68	3·00	3·52
POJ 2878																								
70 in. + 150 N	36·3	21·32	91·5	14·68	4·93	2·84	24·7	19·80	86·6	14·01	2·82	2·99	24·9	20·08	85·5	13·52	2·82	2·49	28·6	20·40	87·9	14·07	3·71	2·78
95 in. + ,,	32·8	21·89	92·3	16·28	4·54	2·69	22·4	20·49	88·4	14·06	2·78	2·55	27·7	20·92	87·9	14·88	3·45	2·49	27·6	21·10	89·5	15·17	3·47	2·58
120 in. + ,,	36·9	22·22	92·5	14·95	5·29	2·99	23·4	20·55	90·4	15·64	2·96	2·63	27·1	21·18	88·1	14·46	3·45	2·42	29·1	21·32	90·3	15·02	3·85	2·68
130 in. + ,,	29·3	22·48	93·6	14·54	4·36	2·64	20·9	20·65	90·0	13·68	2·71	2·47	25·7	21·77	88·6	16·14	3·32	2·35	25·3	21·63	90·7	15·45	3·44	2·3
Mean .	33·8	21·98	92·5	15·11	4·78	2·79	22·8	20·37	88·8	14·35	2·82	2·66	26·3	21·00	87·5	14·75	3·26	2·46	27·7	21·11	89·6	14·93	3·62	2·6
C. D. for significance between any two varieties	2·4	0·089	...	...	...	0·26	2·40	0·49	...	...	...	0·27	2·1	0·79	...	...	...	0·22	1·50	0·456	...	...	...	0·25
C. D. for significance between any two treatments	6·9	0·162	...	...	...	0·42	5·20	0·87	...		...	0·48	4·7	1·43	...	...	...	0·39	3·2	0·821	...	...	...	0·43

POJ 2878 was harvested 12 months after planting and Pundia a month later as the latter was a late-maturing variety. In the case of cane tonnages a deleterious effect of 130 in. is visible throughout the period of experimentaton in both the varieties and although this has not been significant every year, the average figures for the three years of experimentation have brought it out clearly when the seasonal effect is excluded. As regards the other treatments, fluctuations in tonnages are negligible except in the treatment of 120 in. during the season of 1934-35 in which significantly low yields are obtained for Pundia. This is, however, traced to the lying of the majority of plots in this treatment on the western border of the block where the growth was generally poor owing to the deleterious effect of the wind. The weight per cane also shows in general a progressive fall with increased waterings. From the standpoint of brix and purity, the treatment of 130 in. comes out the best followed by those of 120 in. and 95 in. while the treatment of 70 in. has shown a definite delay in maturity. In spite of this higher brix and purity, the figures for either commercial cane sugar as calculated by Srivastava's formulae or of *gul* (Table VII) reveal a definite inferiority of 130 in. There is also a distinct evidence of the increase in the fibre content in the case of 130 in. for both the varieties. It would be thus evident that there is a progressive rise in brix and purity with increased waterings which is quite distinct in the case of 130 in. as against 70 in. while the cane tonnages show the reverse order in these two treatments. As would be shown in section II, this is found to be mainly due to leaching down of assimilable nitrogen and lowering of the microbiological activity by such heavy irrigation as given in 130 in. clearly bringing out the necessity of higher nitrogenous top-dressings with such high irrigation.

(7) *Quality of* gul. Samples of *gul* were analyzed during the season of 1935-36 in order to determine the causes of the variable colour of *gul* in the different treatments. As a rule, *gul* of POJ 2878 is darker in colour than that of Pundia and when judged by the colour standards is generally inferior to it. It is, however, harder and does not rapidly sweat in the humid climate. Some of the analytical figures are given in Table VII. There is a definite indication of the fall in glucose, ash, amide N and total nitrogen with increasing quantities of irrigation. In the case of mineral constituents the results are not consistent; but in general Pundia contains less of ash and a greater quantity of it is in the form of silica than is the case with POJ 2878. The better colour of *gul* seems to be thus related to low ash

TABLE VII

Data of gul *analysis and its valuation*

Variety and treatment	Ash per cent	Ash insoluble in HCl per cent of the total	Glucose per cent	Amide N per cent	Total N per cent	K_2O per cent	P_2O_5 per cent	CaO per cent	MgO per cent	Na_2O per cent	Colour standards by tintometer readings	*Gul* tons per acre—Average of 3 years	Commercial value—Average of 3 years	Profit
													Rs.	Rs.
Pundia														
70 in.	2·67	15·15	28·79	0·0100	0·107	0·95	0·046	0·167	0·033	0·045	4	3·13	321·23	36·30
95 in.	2·25	10·34	28·79	0·0064	0·077	1·18	0·210	0·198	0·076	0·173	3	3·24	362·75	59·38
120 in.	1·93	9·00	24·38	0·0040	0·044	0·56	0·225	0·176	0·090	0·106	2	2·92	326·92	16·96
130 in.	1·59	4·77	25·72	0·0027	0·054	0·77	0·207	0·161	0·057	0·089	1	2·88	349·31	38·36
Mean	2·11	9·82	26·92	0·0058	0·071	0·87	0·167	0·176	0·064	0·103	...	3·04	340·05	37·75
POJ 2878														
70 in.	3·92	3·35	23·73	0·0194	0·157	1·43	0·213	0·229	0·233	0·127	6	3·36	329·00	42·7
95 in.	3·21	3·36	18·51	0·0143	0·104	1·63	0·209	0·157	0·169	0·168	5	3·37	330·10	32·7
120 in.	2·72	4·63	8·32	0·0124	0·085	0·59	0·071	0·139	0·049	0·059	5	3·62	354·50	39·2
130 in.	2·79	4·55	9·14	0·0107	0·106	1·68	0·056	0·249	0·072	0·113	4	3·28	336·60	26·3
Mean	3·16	3·97	14·93	0·0142	0;113	1·33	0·137	0·194	0·131	0·117	...	3·41	337·55	35·2

NOTE—The market valuation of *gul* is as follows:

	Pundia	POJ 2878
70 in.	Rs. 11	Rs. 10/8
95 in.	Rs. 12	Rs. 10/8
120 in.	Rs. 12	Rs. 10/8
130 in.	Rs. 13	Rs. 11/-

content and low amide and total nitrogen content. Further work on the interaction of different constituents affecting the quality of *gul* is in progress and will be published in a separate paper.

The quantity of *gul* produced per ton of cane is dependent upon its brix and thus the *gul* per acre from POJ 2878 is more than that of Pundia although from the standpoint of tonnages Pundia has come out superior. So also the large fall in tonnages observed in the case of 130 in. is not similarly reflected in the *gul* owing to the improvement in the brix by this treatment. The better-coloured *gul* obtained in this treatment also fetches about two rupees more per *palla* of 240 lb. as compared to that in 70 in. in the case of Pundia. The finer differences in colour in the different treatments as obtained by tintometer readings were not, however, appreciated by the market who did not show any graduated variation in valuation. In the case of POJ 2878, the valuation is practically similar in all the treatments, the variation being two to four annas only per *palla*. Taking all these factors into consideration it would be seen that the treatment of 130 in. becomes unprofitable in the case of POJ 2878 in case the water used for irrigation is charged on volume basis ; while in the case of Pundia, this is not evident owing to the higher price obtained in this treatment. As regards other treatments, 95 in. has shown the highest profit in the case of Pundia and 70 in. in the case of POJ 2878. It would be thus evident that lower waterings are likely to be more profitable than higher ones.

(8) *Residual effect.* Surgarcane is grown in three years' rotation of cane, *rabi jowar* and sunn ; and the residual effect of the water treatments was determined on both the following crops. The yield data are given in Table VIII as average for the three years succeeding the three sugarcane crops. In the case of *rabi jowar*, the varietal effect is clearly visible, the yield after Pundia being significantly better than that after POJ 2878. There are also indications of the adverse effect of the increased quantities of water. In the case of sunn the results are conflicting, suggesting no effect of either varieties or treatments on its yields. Perhaps the treatment effect has not lasted long as there was only a single crop of cane, but considering the data of *jowar* there seem to be sufficient indications that the deleterious effect of higher waterings such as 130 in. will be accentuated after a series of cane crops in the same land under this manurial treatment. This is also confirmed by the percentage variation in the total nitrogen of the soil after harvest from the initial nitrogen content given in columns 4 and 5 of Table VIII. These figures clearly show a progressive fall in total nitrogen

TABLE VIII

Data to determine the residual effect

—	Yield of *jowar* per acre. Average of three years—1934 to 1937	Yield of sunn per acre. Average of three years—1935 to 1938	Per cent variation in total nitrogen over the preliminary nitrogen content—1934	
			0—12 in.	12—24 in.
1	2	3	4	5
Pundia—	Lb.	Lb.		
70 in.	3057	9430	+21·6	+9·3
95 in.	2562	8992	+6·6	+3·5
120 in.	2900	12092	+7·0	+3·6
130 in.	2520	10045	—6·6	—12·5
Mean	2760	10140	7·05	1·0
POJ 2878—				
70 in.	2675	11300	+8·7	—6·1
95 in.	2650	8680	+16·3	—6·6
120 in.	2557	10745	+2·3	—5·1
130 in.	2500	9000	+3·5	—5·1
Mean	2596	9931	7·7	5·7
C. D. for significance between varieties	140	817	...	...
C. D. for significance between any two treatments	280	1635	...	...

with increased quantities of water in the case of both the varieties. Further, POJ 2878 seems to be more exhausting of nitrogen than Pundia and the yield of *jowar* has definitely supported this as shown above. It would be thus evident that in the case of 150 lb. N as top-dressing, the treatment of 130 in. not only gives low cane tonnages during the season of its application but it further reduces the nitrogen content of the soil which adversely affects the yields of the succeeding crop of *jowar*.

II. TOTAL DELTA : MOVEMENT OF IRRIGATIONAL WATER AND NITRATES IN RELATION TO PLANT GROWTH

Investigations in developmental phases of the cane plant described in section I have given sufficient evidence of the deleterious effect of 130 in. during later stages of the growth phase, which is also well reflected in the final cane tonnages. In the case of other treatments as 70 in., 95 in. and 120 in. not much variation in cane tonnages is observed. Although there had been some adverse effect on growth in 70 in. during the early growth phase, it was obliterated by the later growth and eventually the cane tonnages were practically similar in all the three treatments. Thus if one is to go by these investigations only, one can definitely conclude that from the standpoint of the performance of the various plant phases leading to cane tonnages, the treatment of 70 in. is as good as the other two and therefore higher irrigation than what is given in this treatment should not be necessary under field conditions for the various developmental phases leading to cane tonnages. Studies in the movement of

irrigational water in all these treatments have, however, revealed a different trend and this is described in the following pages.

Methods

Soil moisture was determined by drying a quantity of soil sample in an air oven at 110°C. till a constant weight was obtained. As planting was done by ridge and furrow method at a distance of 4 ft. between furrows, soil samples were collected in the portion of the balk just midway between the level of the irrigational water mark and the bottom of the furrow. In order to fix the spots at start in the plot, a string was laid diagonally and the spots were marked on alternate balks where the string touched the balk. Four such spots were selected in each plot and the soil samples obtained from them were filled in one bottle and taken to the laboratory for moisture determinations. Immediately after taking the sample, this spot was marked with a peg and the next sample was taken just opposite to this. The succeeding periodic samples were taken at one-foot distances from the previous spots in the longer line of the furrows till the ring portion of the plot is reached, when similar procedure is followed again.

Soil samples were collected a day before and three days after every irrigation throughout the life-cycle of the crop. Daily determinations of soil moisture during a few irrigational intervals at start had shown that three days were necessary in this soil for rapid gravitational movements of irrigational water applied and the figure of percentage moisture obtained after three days closely corresponded with the one obtained in the laboratory by the centrifuge method of Briggs and McLean [1910]. Samples for moisture were collected at one-foot depths up to *murum*. The number of samples thus varied from year to year depending upon the depth of the soil which fluctuated from 24 in. to 48 in. The block under experimentation during the first year had a minimum depth while one under the third year's experimentation the maximum one. Two plots were selected for each treatment separately per variety and four spots per plot were sampled at each time to get an average sample, thus getting duplicate readings per variety.

Care was taken to determine whether there could be any contribution from *murum* sub-stratum to the water requirement of the plant by capillary rise. As sampling in *murum* by an augur was not feasible, these studies were carried out in a very shallow soil having a soil depth of about 6 in. and samples were collected of both soil and *murum* by digging a pit up to 3 ft. depth. Certain portion of this area was planted with sugarcane while the other was left fallow. When the plants were about six months old, soil samples were collected at four spots firstly at two days after irrigation in both the cropped and uncropped portions, as the soil was light, and next after 37 days when the plants showed signs of wilting. No irrigation was given during this period. The results are given in Table IX.

Table IX

Capillary rise through murum

(Per cent on oven-dry basis, average of four determinations)

—	Depth	Cropped: Moisture per cent 2 days after irrigation (30-3-35)	Cropped: Moisture per cent at wilting—37 days after irrigation	Cropped: Fall in moisture (Difference of Cols. 3 & 4)	Uncropped: Moisture per cent 2 days after irrigation (30-3-35)	Uncropped: Moisture per cent at wilting—37 days after irrigation	Uncropped: Fall in moisture (Difference of Cols. 6 & 7)
1	2	3	4	5	6	7	8
Soil	0—3 in.	35·3	11·0	24·3	36·8	14·7	22·1
"	3—6 in.	33·1	15·0	18·1	32·5	19·8	12·7
Murum . .	6—12 in.	19·9	16·1	3·8	20·3	18·4	1·9
"	12—18 in.	17·6	15·4	2·2	14·8	17·3	+2·5
"	18—24 in.	16·4	14·8	1·6	14·2	14·2	0·0
"	24—30 in.	15·6	14·3	1·3	14·4	14·4	0·0
"	30—36 in.	13·9	14·8	+0·9	11·5	12·4	+0·9

It would be evident from the data of the uncropped portion that there is practically no capillary rise through *murum* throughout this period. The fall obtained from the first depth of *murum* seems to be due more to the downward movement of water than to its upward movement as could be seen from the rise in the moisture content in the immediately next lower depth. In the cropped

portion, on the other hand, there is a definite fall in the moisture content in the *murum* layers. This is found to be due to the actual uptake of moisture by roots which permeate the soft *murum* and in the case of hard *murum* through the cracks in it. In the experimental plots, however, where the soil depth was 2 ft. and more, root studies have shown no such penetration of roots in the *murum* sub-stratum and as there is no capillary rise through *murum*, the field-moisture studies can be taken as a reliable index of the water requirement of the crop for both transpiration and evaporation.

Nitrates were determined by the phenol-disulphonic acid method. For this purpose, soil samples collected before irrigation for moisture determinations were used only at monthly intervals. In addition, samples were collected from the first foot only from the top of the balk at a few periods before earthing up during the latter two years.

Presentation of the data

(*a*) *Soil moisture*. As the trend in the fluctuations in the soil moisture has been practically similar throughout the three years, the data for one year only are illustrated. The moisture content before each irrigation is graphically represented in Fig. 3. Further, the figures of moisture content before and after each irrigation were separately averaged for the different plant phases and are given in Table X. The figures for the germination phase which extends for six weeks have been excluded as the moisture content in this phase has remained practically above 40 per cent approximating the moisture equivalent of the soil type. Besides, during the first three weeks of the germination phase, the irrigational dose was common to all the treatments, after which the differentiation according to the treatments was followed.

Table X

Soil-moisture percentage 1935-36

Stage		70 in.			95 in.			120 in.			130 in.		
		0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.	0-12 in.	12-24 in.	24-36 in.
1		2	3	4	5	6	7	8	9	10	11	12	13
Formative	1	40·1	38·6	40·2	42·3	41·0	41·3	43·5	42·5	42·7	44·6	43·6	42·5
	2	38·6	36·2	37·6	38·2	36·2	38·4	38·4	37·1	38·1	39·0	40·4	38·8
Grand period (before earthing up)	1	38·4	35·8	36·3	40·8	39·0	39·2	42·5	39·4	40·3	41·6	41·5	40·9
	2	31·1	31·0	31·6	36·1	35·8	35·1	36·2	35·5	35·8	36·9	36·6	36·8
Grand period (after earthing up)	1	39·5	38·2	38·1	40·4	41·2	41·0	43·6	41·9	42·9	41·9	41·9	40·0
	2	35·7	35·8	35·1	37·7	37·9	40·0	38·2	37·5	37·8	37·4	37·4	38·2
Flowering	1	43·3	40·2	39·9	44·4	40·8	40·5	45·6	41·9	42·2	43·4	41·5	40·8
	2	38·9	39·1	38·3	39·7	38·5	40·7	43·1	39·6	40·9	40·3	40·3	41·1
Maturity	1	43·1	41·6	40·1	44·5	44·9	43·8	47·8	44·8	43·6	46·1	43·8	43·0
	2	39·9	41·2	40·8	42·4	41·9	41·1	44·6	43·6	41·4	43·4	43·8	43·3

NOTE—Stage 1—3 days after irrigation
Stage 2—1 day before irrigation

It would be evident from Fig. 3 that in general there is a greater loss of soil moisture during the growth phase leading to the lowering of the moisture content within the irrigational interval of 10 days, and it is only the actual rainfall which has raised it on occasions. Within this period the months of May and June seem to be the months of lowest moisture content or highest water requirement. With the approach of early monsoon conditions the plant starts rapid growth and consequently there is an increased demand for water until changed climatic conditions, e.g. considerable increase in humidity and decrease in maximum temperature are established with the actual break of rains. This early monsoon period is in fact critical in the life of the plant and it is at this time that the moisture content of the soil falls greatly, which in the case of 70 in. has even approached the wilting coefficient of the soil on some occasions. Further, as could be seen from Table X, the irrigational

dose in this treatment is not even sufficient to bring the moisture content to the moisture equivalent of the soil and thus the availability of water remains low throughout the growth phase except when this irrigational dose is supplemented by high rainfall as is apparent from the portion of the curve (Fig. 3) from September onwards. This low moisture content has, in fact, adversely affected the growth phase (Section I). This is further confirmed by pot culture with different moisture levels maintained throughout the life-cycle of the crop. In this case a level of 40 per cent moisture gave 61 per cent higher yields over a level of 30 per cent moisture which was highly significant, while keeping the moisture content at the moisture equivalent has revealed a deleterious effect, there being actually a fall in yield by 10 per cent. The maintenance of soil moisture at about 40 per cent level would be thus conducive to optimum growth of the crop.

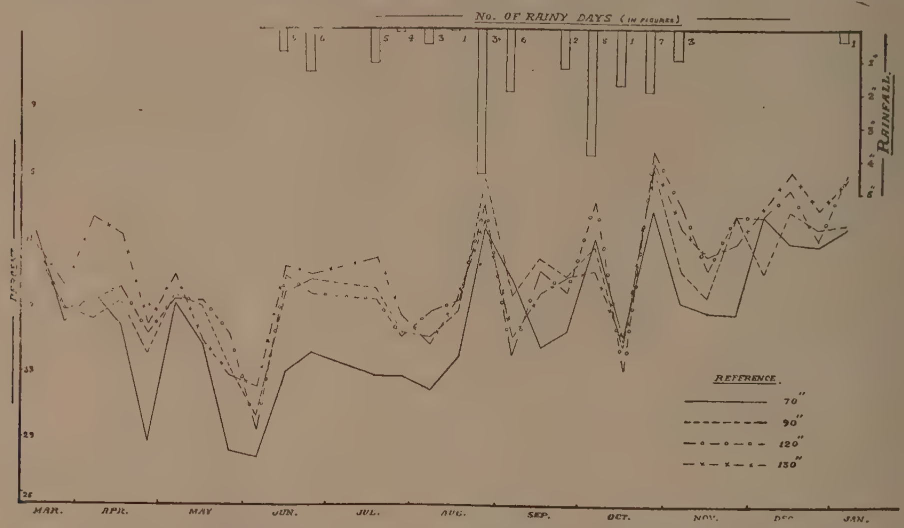


Fig. 3. Periodical moisture studies before irrigation—depth 0-36 in.—1935-36

This insufficiency of irrigational dose in the case of 70 in. is further well illustrated in Fig. 4 in which the dose given per irrigation and the actual quantity of water utilized during a period of 10 days as average of the different phases are represented by pillars. During all the first three phases the irrigational dose has fallen short of the water requirement in this treatment which is more evident during the growth phase. No doubt, as the total delta is inclusive of rainfall, the irrigational dose had to be kept slightly less than what would have been the case if all the total delta could have been given in irrigation. Under field condition the latter alternative would not be possible as some allowance must be made for the ineffective rainfall. It would be further seen that the total water utilized both in transpiration and evaporation in this treatment has come to 67 in. as average of three seasons which is practically the same as the treatment. When one considers that there is a possibility of the adverse effect on growth during the early growth phase in this treatment and at the same time there is practically no margin for any ineffective rainfall the risk in recommending this treatment is obvious.

In the case of the other three treatments, the movement of soil moisture before irrigation is practically similar (Fig. 3), the curves showing mostly higher levels of moisture throughout the life-cycle of the plant than in the treatment of 70 in. The moisture content after irrigation (Table X) remains practically the same as it depends upon the moisture equivalent of the soil and as such in the treatments of 120 in. and 130 in. the irrigational dose is generally excessive of the water-holding capacity of the soil. This would be further quite clear from Fig. 4. In the case of 95 in., the irrigational dose practically equals the quantity of water utilized in evo-transpiration throughout the formative and growth phase. It is even slightly less during the flowering stage ; but this shortage can be more than counterbalanced by the proper adjustment of the irrigational dose by reducing it during the maturity stage in which it is rather in excess. In the case of the other two treatments, however, the pillar for irrigational dose is invariably higher than the one for the water utilized in all the phases, clearly bringing out the possible waste of water in these treatments. The figures for the total water

utilized have shown a progressive rise till the treatment of 120 in. followed by a fall in the last treatment of 130 in. which clearly indicates that the latter treatment has exceeded the limit of optimum requirement.

All these data further indicate that the water requirement of the plant is not constant throughout the entire life-cycle of the plant ; but it varies according to the climatic conditions and the stage of crop growth. It may be evident, therefore, that in order to secure the best advantage from the total delta, it is essential to distribute it in either fluctuating intervals or fluctuating doses and not in uniform periodic doses as has been followed in the present series of experiments based on the general system practised in this tract. On the basis of these soil-moisture studies and the figures of daily water requirement calculated from them, a schedule of fluctuating doses is worked out for an experimental trial in the next series and these data will be discussed in a separate paper.

(*b*) *Evo-transpiration ratios.* These ratios have been worked out from the differences in the soil moisture before and after irrigation for millable canes only as no data are available of the total production of dry matter including all the leaves produced. Figures for transpiration ratios alone cannot be also differentiated as under field conditions it is not possible either to exclude evaporation or to calculate it accurately although some idea of it is got by putting pots filled with soil inside the crop and weighing them at fixed intervals. From practical standpoint also evo-transpiration ratios would be of real use as they give a better idea of the total water requirement of the crop. These are, therefore, given in Table XI for all the three years with the actual quantity of water utilized per acre. Estimation of soil moisture separately in the case of Pundia and POJ 2878 has shown very little variation in the figures for the total delta utilized within a period of 12 months although some fluctuations are observed in the periodical samples. Average figures for the total delta are therefore taken for both the varieties and the evo-transpiration ratios are calculated for each variety on the basis of the dry weight of cane.

These figures reveal the dependence of the evo-transpiration ratios on the dry matter produced, the lesser the production of dry matter, the greater these ratios for the same treatment. The wide fluctuations in these ratios from year to year are due to the predominating influence of climate on growth as already discussed in the previous paper. Further work on the inter-relationship of water and manure have shown that these ratios could be reduced even below 400 for the same water treatment (95 in.) by a suitable selection of the manurial

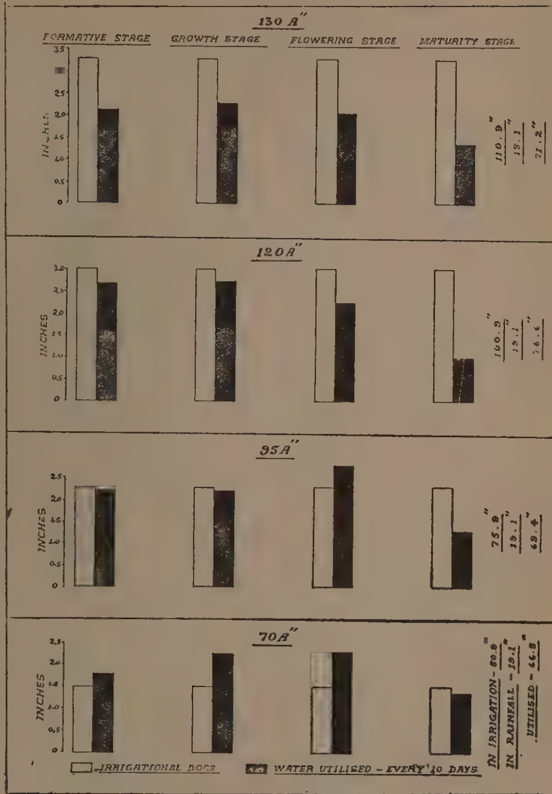


FIG. 4. Periodical water requirement (average of three years—1933-34 to 1935-36)

dose and the varieties. Even in the present case, fluctuations in the ratios for the two varieties are entirely due to differences in the production of dry matter although the total water utilized within a period of 12 months has been practically the same. This is evident from the comparison of the figures of evo-transpiration ratios and the actual water consumed for the years 1933-34 and 1935-36 in the case of 70 in. Although the ratios for these two years varied widely the actual consumption of water during these years was 70·9 and 72·5 acre-inches respectively. It seems, therefore, that from the standpoint of practical irrigation the presentation of the data about actual consumption of water will be of greater utility than of such evo-transpiration ratios which fluctuate largely depending on climate, varieties as well as manuring. It may be remarked here that this figure of the total water requirement is much higher than that obtained by Kulkarni and Inglis [1938]. From their pot-culture work at Hadapsar in the Deccan Canal

TABLE XI

Evo-transpiration ratios

Treatment	Total delta received in irrigation (in.)	Total rainfall (in.)	Total water received by the crop (in.)	Total water utilized both in transpiration and evaporation per acre	Evo-transpiration ratio		Evo-transpiration ratio—Average of 3 years		Remarks
					POJ2878	Pundia	POJ2878	Pundia	
1933-34									
70 in.	52·06	17·94	70	70·9	702	663	..	..	
95 in.	77·06	17·94	95	68·8	755	615	..	..	
130 in.	112·06	17·94	130	73·4	904	720	..	..	
1934-35									
70 in.	48·99	21·01	70	56·2	828	1003	859	868	
95 in.	72·99	21·01	95	60·9	960	1080	*901	876	* The figures are average of two years
120 in.	98·99	21·01	120	62·9	943	1637	1072	1427	
130 in.	108·99	21·01	130	55·9	914	1037	1001	1027	
1935-36									
70 in.	57·64	18·36	70	72·5	1046	939	..	..	
95 in.	76·64	18·36	95	78·5	1017	933	..	..	
120 in.	101·64	18·36	120	90·4	1072	1186	..	..	
130 in.	111·64	18·36	130	84·4	1184	1325	..	..	

NOTE.—During 1933-34 moisture studies were not carried out in the treatment of 120 in.

tract, they have concluded that about 4/5th of an acre-inch of water is all that is required to produce a ton of green cane, or in other words a 40-ton crop requires only 32 in. of water exclusive of evaporation or 47 in. inclusive of the same. It is rather a moot point whether this low figure is entirely due to the location of the experimental work at a place where the humidity is higher than what is obtained here. Their field experiments on irrigational quantities, which were also conducted practically simultaneously, have not, however, supported this low figure. In this case, the treatment of 75 acre-inches has come out the best and as it seems that they have not made any allowance for the rainfall in these water treatments, this figure practically agrees with the treatment of 95 in. of ours. This dissimilarity of results among pot culture and field experiments obtained by these authors has, in fact, justified our viewpoint that for securing conclusive data of practical value, field experimentation of the type described by us will be more suitable.

Nitrates. The nitrate N was determined in the soil samples preserved at monthly intervals from those taken for moisture estimations. These data were calculated as percentage deviation from the original nitrate content of the soil and are illustrated graphically in Fig. 5 for one year only as it almost represents the trend of fluctuations in the different treatments for other years also. In addition, samples were collected from ridge only at a few periods till earthing up during the latter two years. In this case the data are given in Table XII, also for the same year. The results clearly illustrate the fall in nitrates with increased water quantities suggesting leaching of nitrates. This is very well brought out in the data given in Table XII. The comparison of figures with those in the furrow shows that the ridge forms a repository of nitrates which are either accumulated by the capillary rise or by being formed *in situ* due to the intensification of the process of nitrification caused by better aeration. The root-system is found, however, to permeate throughout the mass, and as the growth in the higher water treatments is found to be slightly better at this time with the possibility of greater absorption of nitrates by the plant, the observed fall in nitrates with increasing

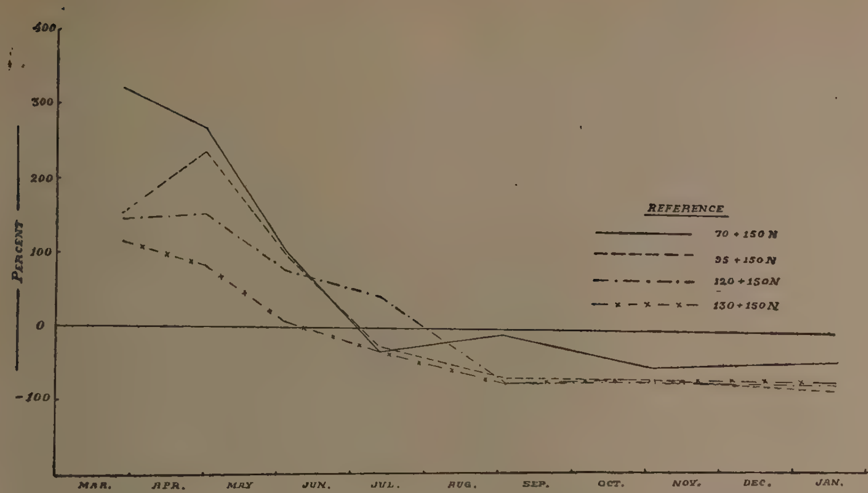


FIG. 5. Periodical deviation of nitric N from preliminary sample—1934-35

quantities of water cannot be entirely attributed to their leaching down to lower layers ; such wide variations, however, do indicate that there must be appreciable loss of nitrates by leaching with increased quantities of irrigation as in the case of 120 in. and 130 in.

TABLE XII

Percentage increase of nitrate nitrogen in ridge over the nitrate content at start 1934-35

Treatment	12 March	18 May	27 June	Actual nitrate N content on 27 June 1934 mg. in 100 gm. of air dry soil
70 in. . . .	609	1079	317	0·51
95 in. . . .	248	414	78	0·22
120 in. . . .	243	98	—10	0·09
130 in. . . .	138	75	—50	0·05

Some laboratory studies were also carried out to see whether such high irrigational treatments do affect the nitrifying power of the soil. For this purpose, soil samples were collected from different treatments at the time of earthing up and were mixed with safflower cake which was to be applied at the time of earthing. These were then immediately filled in earthen-ware pots after making up the moisture content to the moisture equivalent in all the cases. At intervals, a definite portion of the soil was removed and ammonia and nitrates were determined. For ammonia, the soil was distilled with MgO. Every fortnight the moisture content of the soil was made up to the moisture equivalent and care was taken to see that it never fell below 35 per cent during the course of experimentation. Periodical data for both ammoniacal and nitrate N as percentage of the total N are given in Table XIII. The results indicate consistent diminishing microbiological activity leading to less mineralization of cake nitrogen in the soil in the case of 130 in. This low microbiological activity suggests that such heavy irrigation is not conducive to the maintenance of proper tilth required for the purpose and as a result, a larger portion of

TABLE XIII

Ammonification and nitrification of safflower cake percentage of total N

Treatment	15 days		1 month		2 months		3½ months		4½ months		Total mineralization
	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	
Cake + 70 in. .	14·4	0·20	20·9	2·2	17·3	6·8	11·5	9·2	8·3	7·1	19·6
Cake + 95 in. .	12·5	0·20	19·1	2·6	14·5	7·3	9·7	8·6	6·6	6·1	17·4
Cake + 120 in. .	13·6	0·03	20·4	2·6	13·6	6·4	8·8	8·4	6·5	5·7	17·2
Cake + 130 in. .	11·7	0·03	15·6	1·9	11·7	5·4	7·8	7·0	6·3	5·5	14·4

cake, which is the only top-dressing applied at earthing up time, will remain unavailable. The fall in growth at later stages in this treatment seems to be thus partly due to the non-availability of the cake owing to its less nitrification. In the case of the other treatments, 70 in. have shown slightly better mineralization than the other two.

General discussion and conclusions

The problem of the exact water requirement of sugarcane under field conditions is of extreme importance in the Deccan Canal tract, where sugarcane is entirely grown on irrigation from the canals which are constructed at a great cost. A comprehensive programme of research has been, therefore, planned out in a series of experiments, and the first series described in these two parts comprises investigations on the minimum and also the optimum delta for the same manurial dose. These investigations have been mainly carried out by field experiments after taking proper precautions to maintain accuracy in water quantities by carrying the measured volume of water directly to the field by means of hume pipes without any loss in transit. A continuous record was also kept of the fluctuations in moisture in the field by laboratory studies. These data are given in section II while the developmental behaviour of the plant under varying treatments is described in section I.

Among the four water treatments of 70, 95, 120 and 130 acre-inches, sufficient evidence is available as regards the deleterious effect of 130 in. This harmful effect is found to start only at later stages of the growth phase and is traced to deficiency of mineral nutrients specially nitrates. It has been found that this deficiency is caused by both the leaching down of nitrates and the adverse effect of such heavy irrigation on the microbial activity of the soil, the latter reducing the availability of nitrogen in cake applied as top-dressing at earthing up time. That there is a fall in growth in this treatment is further reflected in cane tonnages, the reduction being quite significant in certain seasons and also in the average of the three seasons when compared to the other treatments. Studies in the residual effect have also revealed a fall in total nitrogen and in the yield of the succeeding crop of *jowar* in this treatment. There is thus sufficient evidence to indicate a close relationship of water and nitrogenous top-dressings. The only point in favour of this treatment has been the early maturity leading to higher brix and purity, and better-coloured *gul*. In the case of Pundia, this *gul* has fetched about two rupees more per *palla* and from the commercial standpoint has made up for the fall in yield as compared to the treatment of 70 in. In the case of POJ 2878, the difference in the colour of *gul* from different treatments was not of sufficient magnitude to attract the attention of the market and the prices have been practically similar in all cases. From the standpoint of commercial cane sugar, it has not also come superior to the other treatments.

Coming to the actual use of water in evo-transpiration this treatment seems to have exceeded the limit of optimum requirement as, while there has been a progressive rise in evo-transpiration with increased deltas up to 120 in., this treatment which is immediately higher to it has shown a tendency towards reduction in this figure. It is not, however, quite clear at this stage as to whether this can be entirely ascribed to the depressed plant activity or to the possibility of the maintenance of higher humidity in this treatment which, as is well known, reduces the transpiration.

Among the remaining three treatments, the treatment of 70 in. has shown some adverse effect on growth during the early growth phase, while the other two treatments have shown similar developmental performance throughout. This decreased rate of growth in the case of 70 in. is found to be due to the deficiency of soil moisture during this period caused by the insufficiency of the irrigational dose and it is only the rainfall of September which raised the moisture content of the soil sufficiently to accelerate the rate of growth. It is, however, observed that this low irrigational dose reduces the loss of nutrients by leaching down to lower layers by constant irrigation and therefore the growth continued in this treatment when it had practically ceased in the case of others. Consequently this treatment eventually made up in growth and also in cane tonnages, thus equalling those of the other two at the time of harvest. There is, however, an indication of the progressive rise in brix and purity with increased water quantities.

It would be thus evident that in case we had not such detailed observations on the developmental performance and the data on soil moisture, we would have without hesitation recommended 70 acre-inches to be the minimum water requirement under field conditions by following the general procedure in vogue of taking cane tonnages as the criterion for finally judging the efficiency of the treatments. It must be, however, remembered that all these water treatments are inclusive of rainfall and under field conditions where rainfall cannot be excluded, some allowance must be made for its precarious nature by reserving a portion of the total delta while fixing the irrigational dose in each treatment. Thus the dose at each irrigation would be slightly less than what would have been the case if the total delta was given in irrigation alone in uniform doses. In the case of 70 in., this irrigational dose has been insufficient on many occasions to make up for the loss of moisture, which has adversely affected the growth

and it is only when it is supplemented by rainfall that this adverse effect has disappeared. It is further observed that the actual loss in evo-transpiration comes to about 67 in. in this treatment, i.e. practically equal to the fixed total delta and there would be thus no margin for the ineffective nature of the rainfall when it comes in torrents—a very common feature in this tract. It would be thus risky to recommend this total delta for adoption in the general agricultural practice in this tract as its success would entirely depend upon the favourable season of well-distributed rainfall.

In the case of 95 in., on the other hand, the periodical irrigational dose almost balances the loss of water during the interval and is thus independent of rainfall. This treatment thus contains sufficient allowance for the ineffective rainfall without any excess at the same time in the irrigational dose. Such is not the case with 120 in. in which the irrigational dose is far in excess of the water requirement throughout all the different phases of plant life. At the same time, both the developmental behaviour and cane tonnages have shown no additional advantage of this higher delta over 95 in. and all this excess quantity is therefore a mere waste. Taking all these factors into consideration, 95 in. is considered to be the minimum water requirement under field conditions and 120 in. to be the optimum one for a manurial dose of 150 lb. N.

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VARIATIONS IN THE MEASURABLE CHARACTERS OF COTTON FIBRES

V. VARIATIONS CAUSED BY CHANGE OF PLACE AND SEASON

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(With Plate XIX and four text-figures)

Many workers have studied the influence of environment on the yield of cotton but only a few have correlated its effect on the quality. Balls [1915] investigated the water requirements of cotton and showed that a deficiency in the water supply would affect the development of lint. Hawkins and Serviss [1930] studied the development of the cotton fibre and incidentally correlated the variations in temperature with lint development. They have not, however, made proper allowances for those due to changes in the plant age. Peirce and Lord [1934] worked on the same cotton grown in two places and found considerable variation in the degree of maturity. Patel and Srinagabhushana [1936] examined the effect of growing the same cottons in three places in Gujarat. They observed appreciable differences in fibre weight per centimeter and maturity. It is proposed to record here the variations observed when the same set of cottons were grown at two different places, Coimbatore and Srivilliputhur, for five seasons. It may be mentioned that at Coimbatore the seeds are sown in September and the pickings are done in February and March. At Srivilliputhur, on the other hand, the plants are grown during the hot weather from March to August and the pickings are done in July and August.

Material and methods

The material was collected from pure strains of Cambodia cotton (*G. hirsutum*) evolved at the Cotton Breeding Station, Coimbatore. In the first year there were 14 strains, in the second 11, in the third 28, in the fourth 9 and in the fifth year 8. The following characters were determined :

1. Seed weight,
2. Lint weight,
3. Ginning percentage,
4. Mean fibre length,
5. Mean fibre weight per centimeter,
6. Unit fibre weight,
7. Standard fibre weight,
8. Number of fibres per seed, and
9. Maturity percentage.

In addition the mode of development of fibres was also studied. The first three characters were determined by taking four lots of 100 seeds each according to the method described by Hilson [1922]. Mean fibre length was obtained by two Balls sorter tests on separate slivers according to the method followed at the Technological Laboratory, Bombay, [Ahmad, 1933]. The unit fibre weight and fibre weight per centimeter were obtained by weighing whole fibres [Ahmad, 1933]. The standard fibre weight was calculated according to the new formula of Peirce [1938]. The number of fibres per seed was obtained by dividing the lint weight per seed by the unit fibre weight [Iyengar, 1934]. The maturity was determined by the use of Gulati and Ahmad's [1936] maturity slide.

For the study of the length and thickness development, flowers of Co 2 were labelled on the day of opening and bolls of various ages were collected and immediately killed in form-acetic-alcohol. Ovules from the middle position of 9-seeded locks were used in the present study. Ovules of 0 to 6 days' age were embedded in paraffin for cutting sections. The sections were cut to 10 μ thickness and stained with haematoxylin. The number of fibres sprouting on the seed surface was counted on the five middle sections and their average was taken. The length and breadth of the middle section were also determined with the help of which the approximate total number of fibres per seed was calculated as shown in the Appendix. Four to six ovules have so far been studied for each of the ages one, two and four days, for each of the two places. Those of 4 to 29 days age from bolls collected at Coimbatore and of 4 to 19 days age in the case of collections made at Srivilliputhur were used for measuring the fibre length. In the latter samples the locks of cotton were immersed, as suggested by Berkley [1939], in boiling water for a few minutes to disentangle the fibres for the length measurement. The fibres sprouting on the right side of the seed, when the funicle is pointing away from the observer, were used for measuring the length. Keeping the seed under water the fibres were gently separated and straightened by means of a needle. The approximate length of the tuft from the centre of the seed was then measured by means of a pair of dividers. Ten measurements were made for each age. For the measurement of wall thickness the fibres of the same region were utilized. A tuft of about 150

fibres was separated by means of a needle and pulled out from the seed. This tuft was gently spread out on the Gulati and Ahmad slide and mounted in a mixture made of equal proportions of water, glycerine and alcohol. Fibre wall-thickness was determined at one place (about the middle) for each fibre by moving the slide on the stage of the microscope. Six tufts taken from different seeds were examined for each age. The diameter of the uncollapsed fibre was determined by mounting and measuring the fibres as in the case of wall-thickness measurement. Six samples from different bolls of the highest available age were studied for each place. The surface area of the seed was determined by the method described by Iyengar [1929 and 1941]. One hundred seeds, in four lots of 25 each, were examined for each of the eight strains studied in the final year. The volume of the seed was also determined by the displacement of kerosene oil.

For statistical analysis Student's method was employed for testing the differences within the same year, and anlaysis of variance was used when differences for all the years were combined together. In the anal sis of variance only six strains which were common to the last four years were utilized, the results for which are found in Table VIII.

Results

The individual results of each character for the five different years are not recorded for the sake of brevity. The mean differences between the two places with their statistical significances are, however, given in Table I. The values for the variance ratio (e^{2z}) along with its significance are given in columns 17 and 18 of Table I. The analysis of variance is found in Table VII.

It will be seen that most of the differences are highly significant and many of the characters behave uniformly in almost all the years. (1) Lint weight, (2) ginning percentage, (3) number of fibres per seed, and (4) mean fibre length exhibit the same kind of behaviour in all the five years, the first three characters being greater and the last one smaller at Coimbatore (Fig. 1).* Two other characters also, viz. standard fibre weight and the proportion of mature fibres, behave alike in four out of the five years, the former being higher and the latter lower at Coimbatore. In three of the five years fibre weight per cm. is significantly greater at Coimbatore. In the other two years the differences are either way and both of them are not significant. Unit fibre weight and immature fibres behave differently in different years. In only one year the seed weight records a significant increase at Srivilliputhur.

*In Fig. 1 the differences expressed as percentage of the mean are given for all the properties except mature and immature fibres percentages, for which the actual differences are recorded

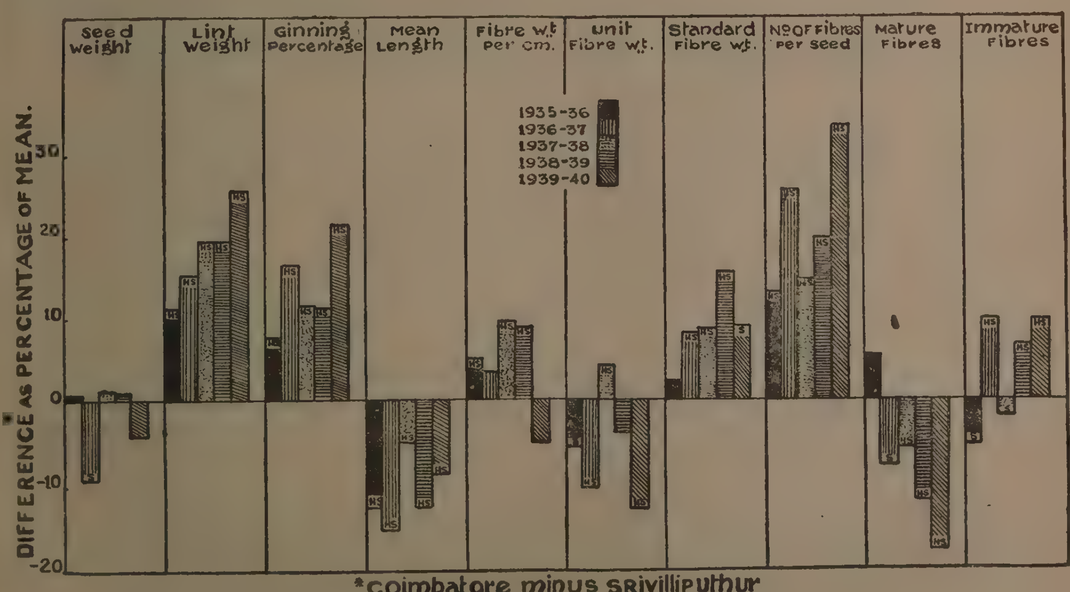


Fig. 1. Variation of characters with change of place

TABLE I

Difference between Coimbatore and Srivilliputhur

Property	1935-36			1936-37			1937-38			1938-39			1939-40			By analysis of variance		1939-40 September to March at both places		
	Difference*	t	Significance	Difference	t	Significance	Difference	t	Significance	Difference	t	Significance	Difference	t	Significance	e^{2z}	Significance	Difference	t	Significance
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Number of pairs of samples		14			11			28			9			8		7			5	
Seed weight in m. gm.	0·42	0·31	N	—10·5	2·78	S	1·71	0·73	N	1·67	0·56	N	—4·38	1·70	N	22·7	HS (—)	8·0	5·1	HS
Lint weight in m. gm.	6·54	7·30	HS	9·42	7·85	HS	12·3	15·20	HS	12·11	8·97	HS	15·88	35·54	HS	160·7	HS (+)	11·2	5·9	HS
Ginning percentage	2·55	7·75	HS	5·78	9·25	HS	4·21	10·80	HS	4·33	18·9	HS	7·25	21·18	HS	322·8	HS (+)	3·0	5·3	HS
Fibre length in inch	—0·114	8·50	HS	—0·140	16·05	HS	—0·051	3·70	HS	—0·116	6·28	HS	—0·086	7·67	HS	134·5	HS (—)	0·01	0·98	N
Fibre weight per cm. in 10^{-6} gm.	0·086	3·15	HS	0·046	1·29	N	0·130	9·82	HS	0·123	3·42	HS	—0·012	1·37	N	6·6	S (+)	0·08	1·6	N
Unit fibre weight in 10^{-6} gm.	—0·194	2·20	S	—0·360	3·61	HS	0·135	3·28	HS	—0·114	1·07	N	—0·496	3·60	HS	6·5	S (—)	0·22	1·3	N
Standard fibre weight per cm. in 10^{-6} gm.	0·004	0·05	N	0·196	25·10	HS	0·159	8·03	HS	0·252	11·6	HS	0·140	3·25	S	74·0	HS (+)	0·06	1·1	N
Number of fibres per seed in 1000's	2·18	5·05	HS	4·68	6·33	HS	2·58	6·54	HS	3·71	8·17	HS	6·56	9·85	HS	68·5	HS (+)	2·3	2·8	S
Mature fibres per cent	5·29	2·07	N	—7·9	2·83	S	—5·0	4·39	HS	—12·1	4·79	HS	—18·25	7·75	HS	32·2	HS (—)	5·0	2·1	N
Immature fibres per cent	—5·26	2·87	S	9·55	6·70	HS	—1·96	2·34	S	6·3	3·77	HS	10·25	6·26	HS	21·7	HS (+)	1·8	1·0	N

HS = Significant for $P = 0·01$
S = Significant for $P = 0·05$
N = Not significant
*Coimbatore values—Srivilliputhur values

The results of the analysis of variance are substantially in agreement with the findings made above. Lint weight, ginning percentage, fibre weight per cm., standard fibre weight, number of fibres per seed and immature fibres are significantly ($P=0\cdot01$) greater at Coimbatore, while mean length and the proportion of mature fibres are significantly ($P=0\cdot01$) less; unit fibre weight and seed weight are likewise significantly ($P=0\cdot05$) less at this place.

From the foregoing it may be concluded that at Srivilliputhur (1) the mean fibre length is greater, (2) the fibre weight per cm. as well as the standard fibre weight, or in other words, the diameter of the fibre cells, is smaller, (3) the maturity of the fibre is greater, and (4) the number of fibres sprouting on the seed is less. They indicate that the quality of cotton is considerably improved when grown at Srivilliputhur, though it is accompanied by a reduction in the number of sprouting fibres on the seed.

The rate of development of the fibres in the two places may now be considered. The period of growth of the cotton plant is about a month shorter at Srivilliputhur than at Coimbatore. On *a priori* grounds a reduction in the maturation period of the boll can be anticipated. That means the lengthening phase of the fibre will proportionately get shortened. This will mean that the fibre will be shorter at Srivilliputhur. But actual observations show it to be exactly opposite. It would follow that the rate of lengthening must be greater at Srivilliputhur. A similar reasoning in the case of wall-thickness points to an increased rate of thickening of the fibre of this place. The results obtained show that at Coimbatore the average maturation period (mean of 358 bolls) is $53\cdot7\pm0\cdot23$ days while at Srivilliputhur it (mean of 704 bolls) is only $40\cdot0\pm0\cdot14$ days, i.e. about 14 days shorter. The details of the lint length development are given in Table II and Fig. 2. It will be seen that at Coimbatore the lengthening phase continues up to about 23 days while at Srivilliputhur it ends by the 16th day. The rate of lengthening is considerably higher at the latter place (Fig. 2), the highest value is about 4·55 mm. per day on about the 15th day. The highest rate at Coimbatore is only 3·05 mm. per day. Logistic curves [Mills, 1938] fitted to the data of the length development show that at Coimbatore the length of the fibre, l, is given by $\frac{10,000}{l}=281\cdot61+9206\cdot20\times0\cdot6280^d$ and at Srivilliputhur by $\frac{10,000}{l}=247\cdot79+4597\cdot66\times0\cdot5597^d$, d being the time unit of two days, starting from the fourth day. The development of the secondary wall is recorded in Table III. Bolls of age beyond 53 days

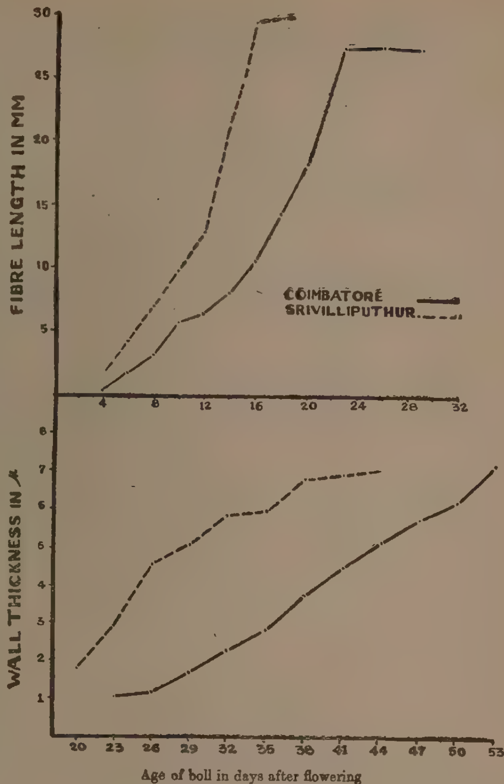


FIG. 2. Length and thickness development of fibres

were not available at Coimbatore while at Srivilliputhur those of 44 days were the oldest obtained. The results show that the maximum wall-thickness of about 7μ is deposited in about (53—23) 30 days at Coimbatore. The same amount of thickening is produced at Srivilliputhur in about (40—16) 24 days only. The rate of secondary deposition is highest in the earlier stage at the latter place, it being as high as $0\cdot36\mu$ to $0\cdot48\mu$ per day. At Coimbatore, on the other hand, the highest rate is at about the middle of the thickening period; the maximum value $0\cdot28\mu$ per day is much less than that a Srivilliputhur. Logistic curves fitted to the data of the secondary thickening show that at Coimbatore the thickness of the wall, t, is given by $\frac{10,000}{t}=1212\cdot46+9428\cdot08\times0\cdot6931^d$ and at Srivilliputhur it is given by $\frac{10,000}{t}=1360\cdot96+3926\cdot82\times0\cdot5559^d$, d being the time interval of three days starting from 23 days at Coimbatore and 20 days at Srivilliputhur.

The mean diameter of the uncollapsed fibre is found to be $22\cdot38\mu\pm0\cdot286\mu$ at Coimbatore and

TABLE II

Length development of fibres in mm. (Mean of 10 determinations in each case)

Age of ovules after flowering	Coimbatore 1939-40				Srivilliputhur 1940			
	Length		Rate of lengthening per day		Length		Rate of lengthening per day	
	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.	Mean ±	S.E.
Days								
4	0·84	0·032			1·79	0·066		
			0·52	0·029			1·24	0·056
6	1·88	0·051			4·27	0·092		
			0·68	0·047			1·37	0·076
8	3·25	0·079			7·01	0·121		
			1·28	0·082			1·42	0·106
10	5·80	0·145			9·85	0·174		
			0·35	0·094			1·50	0·128
12	6·50	0·122			12·85	0·188		
			0·88	0·156			4·45	0·204
14	8·25	0·285	..	..	21·75	0·361		
							3·20	0·482
15	..	..	1·22	0·185	24·95	0·320		
							4·55	0·452
16	10·70	0·236	..	..	29·50	0·320		
							0·20	0·410
17	..	..	2·38	0·196	29·70	0·256		
							0·15	0·317
18	14·45	0·312	..	..	29·85	0·187		
							0·15	0·300
19	..	..	1·98	0·228	29·90	0·234	..	..
20	18·40	0·322			..	..	..	..
			3·05	0·172				
23*	27·55	0·408			..	..	..	..
			0·00	0·207				
26	27·55	0·466			..	..	..	..
			—0·08	0·203				
29	27·30	0·394	..	..	..	..	..	..
Mean	..		1·20		..		1·85	

*As it was thought that the lengthening phase might not extend beyond 20 days after flowering, bolls of age differing by single day only after 20 days were not killed at Coimbatore. At Srivilliputhur this defect did not arise as the lengthening phase ended by 16 days

TABLE III

Degree of thickening in μ for different ages (Mean of six determinations in each case)

Age of ovule after flowering	Coimbatore 1939-40 Wall thickness Mean ±	S.E.	Coimbatore 1939-40 Rate of thickening per day* Mean ±	S.E.	Srivilliputhur 1940 Wall thickness Mean ±	S.E.	Srivilliputhur 1940 Rate of thickening per day* Mean ±	S.E.
Days								
20	..	..	..	..	1·72	0·049	..	..
23	1·05	0·006	..	..	2·93	0·133	0·48	0·011
26	1·16	0·006	0·10	0·002	4·59	0·042	0·36	0·033
29	1·68	0·011	0·19	0·001	5·09	0·150	0·21	0·046
32	2·28	0·002	0·19	0·011	5·85	0·276	0·15	0·034
35	2·81	0·064	0·26	0·010	6·00	0·144	0·17	0·058
38	3·82	0·061	0·28	0·042	6·85	0·211	0·16	0·025
41	4·51	0·241	0·24	0·029	6·98	0·052	0·04	0·040
44	5·24	0·163	0·22	0·052	7·11	0·113	..	..
47	5·80	0·204	0·17	0·063	..	..	..	..
50	6·26	0·340	0·23	0·043	..	..	..	..
53	7·18	0·157	..	..	..	..	..	..
Mean	..	..	0·240	..	..	..	0·279	..

*Mean increase for six days' interval

$21{\cdot}47\mu \pm 0{\cdot}182\mu$ at Srivilliputhur. The difference is statistically significant for the 5 per cent point, indicating that the fibre is finer at Srivilliputhur, which conforms with the finding made previously from the results for the standard fibre weight.

The results obtained for the number of fibres per section and per seed for the different ages are given in Table IV.

TABLE IV

Number of fibres sprouting on the ovule

Age of ovule	Per section: Coimbatore	Per section: Srivilliputhur	On the whole ovule: Coimbatore	On the whole ovule: Srivilliputhur	Diameter of fibre cell in μ: Coimbatore	Diameter of fibre cell in μ: Srivilluputhur
1 day	93	141	6,800	10,400	11·7	14·4
2 days	179	160	12,600	9,000	14·4	14·9
4 days	226	181	10,700	9,500	17·2	16·8
Fully mature seed			19,000	13,000		

It should be stated at the outset that further work is necessary before definite conclusions can be drawn. The following observations may, however, be made tentatively. The mean number of fibres per section is seen to increase with age at Coimbatore but at Srivilliputhur the increase, if any, is negligible. The calculation of the total number of fibres on the whole seed is subject to error. Bearing this in mind it may be stated that the number of fibres per seed is less at Coimbatore on the first day; at Srivilliputhur, however, the differences cannot be said to be significant. Balls [1915] stated that the number of fibres sprouting on the seed was determined by the environmental conditions on the day of flower opening, there being no further differentiation

afterwards. Gulati (1930) and Ayyar and Appanger (1932) and others showed that further sprouting of fibres also does take place. When the present results are considered in the light of the above findings, it looks as if the remark of Balls is correct at Srivilliputhur and that of the others at Coimbatore. It may be mentioned here that the cotton which Balls (1915) studied was also grown in summer as at Srivilliputhur. Further confirmation is, however, essential to substantiate this conclusion.

Between the two places the difference in the number of fibres is very conspicuous in the one day-old ovule. The development of the fibre is also considerably different as can be seen in Plate XIX. The Coimbatore ovule has on it very small protrusions, hardly visible, while the Srivilliputhur one shows out the fibres very clearly. The number is also much more at the latter place. In ovules of age of two days the number of fibres per section appears to be the same in both the places, but in four days old ones the Coimbatore value rises very much higher than the other. Thus starting with much smaller number at Coimbatore it overtakes and leaves behind the Srivilliputhur value by the fourth day.

The diameter of the fibre cell at the point of sprouting appears to increase with age at Coimbatore, while at Srivilliputhur the value for the fourth day alone is greater than the other two. Further determinations are to be made on this point.

To account for the reduced number of fibres per seed at Srivilliputhur, Dr Nazir Ahmad suggested that the surface area of the seed be determined at both the places to see if it is less at Srivilliputhur. The results obtained are given in Table V.

TABLE V

Differences in seed characters (Coimbatore minus Srivilliputhur)

	Area × K	Seed weight in mgm.	Seed volume in c.c.	Density of seed in gm./c.c.	No. of fibres per seed in 1000's	No. of fibres per unit area × K'
Value . . .	—0·485**	—0·0055	—0·0098*	0·0274 n*	6·56** 34 per cent of Cbe value	3·72** 46 per cent of Cbe value
S.E. . . .	0·0967	0·0034	0·0032	0·0137	1·62	0·544

** significant for $P = 0·01$ n* Near significance for $P = 0·05$ * significant for $P = 0·05$

It will be seen that the surface area, instead of being less, is significantly more at Srivilliputhur. As a consequence the number of fibres per unit area of the seed surface gets reduced still further at this place. The difference in this character is as high as 46 per cent of the Coimbatore value, while the corresponding difference in the total number of fibres on the whole seed is only 34 per cent.

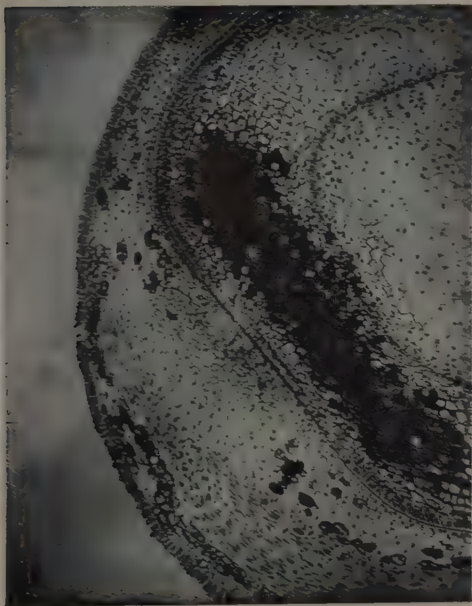
The difference in the surface area is seen above to be significantly greater at Srivilliputhur. But it was found that the seed weight was not significantly different. These two findings are apparently contradictory. But the results obtained for the seed volume offer an explanation, the volume being significantly greater at Srivilliputhur. The higher volume reduces the density of the seeds here, the difference in which though not statistically significant is near the critical value.

DISCUSSION OF RESULTS

The changes in the climatic and fertility factor in the two places can now be examined with a view to correlate the observed variations in fibre characters with any of them. It will be seen from Fig. 3 that the temperatures during the earlier phases of the plants' growth at Srivilliputhur are considerably higher than those of the corresponding stages at Coimbatore. The mean‡ weekly temperature at the latter place ranges from 73°F to 80°F, except in the last four weeks (Fig. 3), whereas at Srivilliputhur the mean temperature is never below 82°F, with a maximum reaching to 88°F. During the grand period of the plants' development and during flowering and boll-formation the mean temperature at Coimbatore is very low (73°F. to 77°F.) while at Srivilliputhur it is much higher (85°F. to 88°F.). The higher temperature is associated with greater solar radiation. Even in the general shape of the temperature curve there is a considerable difference. While at Coimbatore the temperature falls and

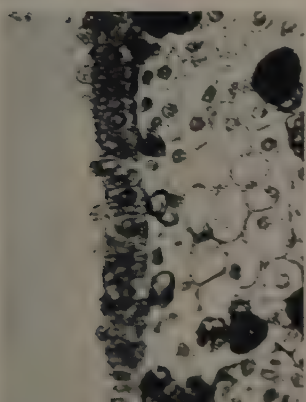
‡The mean weekly temperature was obtained by determining on the thermohygrograph chart the area enclosed by the temperature curve, the two 8 o'clock lines at the beginning and the end of the week and the zero degree line and calculating the mean temperature therefrom. The mean weekly relative humidity was similarly determined from the relative humidity curve, the 8 o'clock lines being used in this case.

Section of a one day old ovule of the strain of Cotton Co2 (*G. hirsutum*)

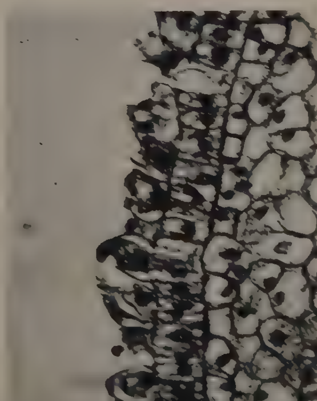


Grown at Coimbatore (× 100)

Grown at Srivilliputhur (× 100)



Grown at Coimbatare (× 400)



Grown at Srivilliputhur (× 400)

then rises (Fig. 3) during the life of the plant, at Srivilliputhur it appears to rise and then fall.

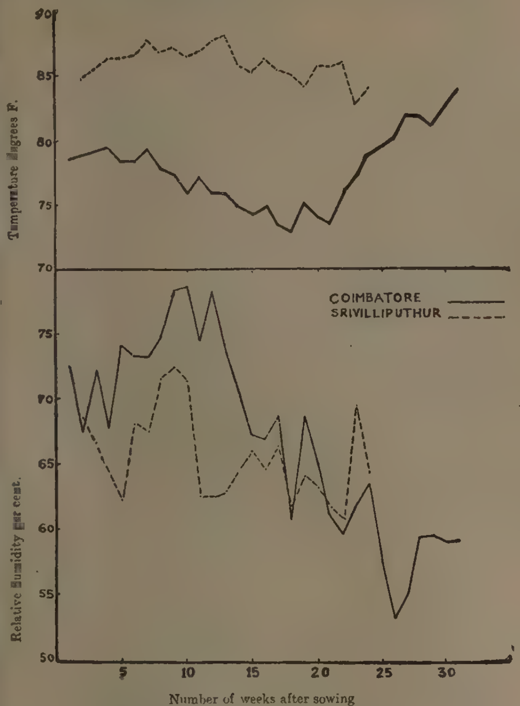


FIG. 3. Variation of temperature and relative humidity (Mean value for three years)

Coming next to the mean weekly relative humidity it will be seen that there are distinct differences (Fig. 3) between the two places, though not as conspicuous as in temperature. At Coimbatore, after a preliminary rise there appears to be a gradual fall with the advance of age, while at Srivilliputhur the general trend is not distinct. Between the 10th and the 16th weeks after sowing, that is, when most of the floral buds are being formed, the mean weekly relative himidity is considerably higher at Coimbatore (Fig. 3).

With regard to the rainfall it may be stated that the two places receive nearly similar amounts; the distribution of rainfall is also fairly similar. The quantity of water given in the irrigations is slightly more at Srivilliputhur.

For the comparison of the relative fertility of the soils of the two centres the soils were analyzed by the Government Agricultural Chemist and their results are given in Table VI. The Government Agricultural Chemist remarks on them: 'In general the soil from the Srivilliputhur taluk contains mechanically more finer fractions than the Coimbatore soils. The available phosphoric acid and pH of the surface soil from Srivilliputhur taluk are more favourable and also the water-soluble salts are less as will be evident from the values obtained from their electrical conductivity'. The soil at Srivilliputhur may, therefore, be taken to be relatively more fertile than the soil at Coimbatore.

Summing up the differences it may be stated that at Srivilliputhur (1) the temperature and solar radiation are considerably higher, (2) the

TABLE VI

Results of analysis of 12 samples of soil from Cotton Breeding Station, Coimbatore and Srivilliputhur

Property in	Field No. 7, C. B. S., Coimbatore				Field No. 8, C. B. S., Coimbatore				Srivilliputhur			
Depth in.	0-6	6-12	12-24	24-36	0-6	6-12	12-24	24-36	0-6	6-12	12-24	24-36
Lab. No.	2457 38-39	2458	2459	2460	2461	2462	2463	2464	199 39-40	200	201	202
Moisture	3·58	3·66	4·16	4·36	3·49	3·82	4·25	3·89	4·75	5·21	5·23	5·49
Nitrogen	0·052	0·043	0·047	0·045	0·046	0·043	0·044	0·046	0·068	0·031	0·021	0·018
Av. potash	0·022	0·017	0·013	0·0073	0·025	0·021	0·016	0·015	0·025	0·014	0·011	0·012
Av. phos. acid	0·029	0·0175	0·0097	0·0020	0·017	0·013	0·0093	0·010	0·058	0·016	0·0059	0·0035
Clay	33·59	33·37	37·92	36·29	33·43	34·82	37·76	36·89	35·96	37·56	38·25	39·37
Silt	5·71	9·13	8·40	11·76	8·91	9·05	10·18	10·98	11·34	12·24	11·87	12·48
Fine sand	21·51	21·01	23·40	22·10	22·72	23·79	22·41	22·28	20·84	19·08	19·40	17·84
Coarse sand	35·53	36·34	28·09	21·96	34·53	32·32	29·23	28·89	31·57	32·47	32·04	30·11
Acid solubles	3·66	0·15	2·10	7·82	1·41	0·02	0·42	0·96	0·29	..	..	0·20
Max. water holding capacity	47·42	47·67	48·62	51·17	38·69	43·64	41·59	44·12	53·60	52·90	50·56	49·61
pH	8·72	8·46	8·44	8·68	8·96	8·29	8·40	8·08	8·26	8·23	8·51	8·14
Electrical conductivity × 10^6 Mhos	21·96	21·98	25·07	30·73	18·35	20·77	22·82	23·00	19·10	15·00	16·04	17·47

relative humidity during the period of flowering is less, (3) the soil is more fertile and less alkaline, and (4) slightly larger quantity of water is given in the irrigations.

The effect of each of the above factors may now be considered in the light of available literature. Recent work of Ayyar *et al.* [1940] has shown that the effect of large differences in irrigation is negligible on the fibre characters. Hence the slightly increased quantity of irrigation water at Srivilliputhur can hardly be responsible for the large differences observed in the fibre properties. Regarding fertility of soil or manurial treatment on quality of lint produced, fairly good amount of literature is available. The general trend of the conclusions is that the changes in inherent soil fertility or application of manure do not cause much differences in the quality except in very poor soils. Coimbatore soil not being very poor, the fertility factor may not be the cause of the considerable differences observed. It has to be considered that greater solar radiation, higher temperature and lower relative humidity prevailing during the flowering period at Srivilliputhur bring about the changes.

It is well known that heat and light stimulate the growth of a plant, the action being either direct or indirect. Each character has different ranges of temperature favourable for growth and as such the rate of development of a particular character may depend on the rise or fall in temperature up to a certain point [Stiles, 1936]. In the case of cotton, it appears from the present study that the higher temperature (within the range studied) accelerates the rate of length development and the rate of secondary thickening while it retards the sprouting of fibres on the seed and the size of their diameter.

Regarding the number of fibres sprouting on the seed, Balls [1915] has stated that it is influenced by the environment on the day of flowering. Later workers, e.g. Gulati [1930], Ayyar and Ayyangar [1932] and others, have shown that further sprouting of fibres also takes place after the day of flowering. The present results do, however, point out that environment does influence the production of fibres on the seed, the reduction in number being associated with higher temperature, greater solar radiation and lower humidity. By cutting sections of seeds of different ages, from both the places, it is proposed to verify by actual counts whether the number of fibres sprout is less at Srivilliputhur and if so at what stage. Studies in this direction are in progress.

It is of interest to note here that the production of smaller number of fibres per seed is associated with longer length and finer cell diameter.

The differences observed in the foregoing may have been caused by conjoint effects of change of both place and season. By growing the same strains in both places during the same season it would be possible to eliminate the effect of the season. This was done during September to March of 1939-40. It does not mean, however, that the effect of the season is completely eliminated, for the climatic factors are not identical in both the places even during the same season. In fact, the temperature at Srivilliputhur is still higher than that at Coimbatore, though not as much higher as observed before. Five strains were grown at both these places and the differences observed are recorded in the last columns of Table I. It will be seen that the seed weight, lint weight, ginning percentage and number of fibres per seed are significantly higher at Coimbatore. The differences in the other characters are not significant. When these differences are compared with those previously observed, that is, when both place and season are different it will be seen that the variations in lint weight, ginning percentage and number of fibres per seed run parallel, though the magnitude of the difference is less in the present case. This means that the production of fibres on the seed surface is influenced by both place and season. The increased length, reduced fibre weight per cm. and standard fibre weight and improved maturity are, however, caused by the higher temperature and solar activity and not by place.

It was stated above that the reduction of the lint weight and the number of fibres on the seed surface at Srivilliputhur was partly caused by the place. It has been mentioned earlier that even during the same season the temperature at Srivilliputhur is greater. Therefore what is apparently due to the place may be due to the higher temperature. In that case even the smaller variation in temperature appears to influence the production of fibres. That means fibre production on the seed appears to be more sensitive to changes in temperature than fibre length, fineness or thickness development.

Recent work by Anderson [1940] has revealed that the internal temperature of cotton bolls is considerably higher than the atmospheric temperature, when the bolls are exposed to sunlight. It is proposed to study the effect of temperature on the production of fibres on the seed and other fibre properties by examining bolls exposed to sun and those covered from the sun's rays.

At Srivilliputhur the higher temperature is, as already stated, associated with greater quantity of solar radiation. The growing of the plants in a hot-house would eliminate the radiation effect, leaving the temperature effect alone. It would then be possible to state whether the difference produced is caused by the temperature or by the solar radiation. Separation of the

Table VII

Variance : mean square and significance

Variance due to	Degrees of freedom	Seed weight in m. gm.	Lint weight in m. gm.	Ginning percentage	Mean length in inch	Fibre weight per cm. 10^{-6} gm.	Unit fibre weight 10^{-6} gm.	Standard fibre weight 10^{-6} gm.	Number of fibres per seed in 1000's	$\sin^{-1}\sqrt{\frac{\text{Mature fibres per cent}}{100}}$	$\sin^{-1}\sqrt{\frac{\text{Immature fibres per cent}}{100}}$
Place	1	540·2 HS	1188·1 HS	297·0 HS	0·1281 HS	0·0554 S	0·4524 S	0·4740 HS	175·14 HS	410·1 HS	243·9 HS
Years	3	190·7 HS	63·0 HS	15·4 HS	0·0058 HS	0·0094 N	0·1418 N	0·0107 N	13·21 HS	49·8 S	31·6 N
Strains	5*	1046·3 HS	144·3 HS	11·4 HS	0·0021 N	0·1404 HS	0·8359 HS	0·0914 HS	9·13 S	30·0 N	36·6 S
Residual	38*	23·82	7·39	0·92	0·00095	0·00837	0·06960	0·00641		12·73	11·26

*For seed weight, lint weight, ginning percentaage and number of fibres per seed the last five strains of Table VIII have been used. Hence for those properties the degrees of freedom for the strains become 4 and for the residual 31

Table VIII

Results for seven strains grown at Coimbatore and Srivilliputhur for four years

Cotton		Seed weight in m. gm.		Lint weight in m. gm.		Ginning per cent		Length in inch		Fibre weight /cm. in. 10^{-6} gm.		Unit fibre wekght in 10^{-6} gm.		Standard fibre weight 10^{-6} gm.		No. of fibres per seed in 1000's		Mature fibres per cent		Immature fibres per cent	
		Co.*	Sri.*	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.	Co.	Sri.
Co. 2	36–37	134	119	73	59	35	33	0·95	1·05	1·51	1·58	3·65	4·23	1·75	1·57	19·9	13·9	55	70	22	9
	37–38	129	130	71	56	35	30	0·92	1·00	1·62	1·58	3·78	4·01	1·87	1·72	18·8	14·0	50	63	17	19
	38–39	..	121	..	53	..	30	0·92	0·97	1·76	1·64	4·12	4·04	1·91	1·71	..	13·1	60	65	15	13
	39–40	132	136	71	48	35	26	0·92	1·02	1·58	1·56	3·70	4·03	1·81	1·65	19·2	11·9	53	60	18	11
3915 F	36–37	108	114	64	52	37	31	0·90	1·11	1·23	1·29	2·82	3·64	1·51	1·38	22·6	14·3	50	61	27	14
	37–38	109	122	69	59	39	33	0·93	1·00	1·36	1·22	3·22	3·09	1·59	1·41	21·5	19·0	51	55	20	25
	38–39	116	125	68	60	37	32	0·90	1·14	1·40	1·37	3·19	3·96	1·67	1·32	21·3	15·2	53	75	25	8
	39–40	120	128	69	56	36	30	0·95	1·06	1·27	1·50	3·06	4·06	1·51	1·51	22·4	13·8	50	75	22	6
3915 Q	36–37	104	117	62	52	37	31	0·93	1·09	1·41	1·25	3·33	3·45	1·65	1·30	18·6	15·1	55	65	24	13
	37–38	107	114	66	52	38	32	0·91	1·01	1·33	1·16	3·16	3·10	1·61	1·41	21·6	17·4	51	55	23	28
	38–39	114	118	68	56	37	32	0·92	1·03	1·32	1·27	3·09	3·34	1·48	1·28	22·2	16·6	57	70	20	11
	39–40	112	127	65	53	37	29	0·91	1·04	1·31	1·47	3·02	3·88	1·58	1·49	21·6	13·7	49	66	23	9
4456	36–37	93	109	55	46	37	30	0·92	1·05	1·36	1·28	3·18	3·40	1·65	1·43	17·3	13·5	49	56	24	17
	37–38	92	92	58	48	38	34	0·92	0·93	1·26	1·18	2·95	2·69	1·48	1·34	19·7	17·8	52	57	22	21
	38–39	106	104	61	46	36	31	0·91	1·04	1·42	1·20	3·27	3·19	1·70	1·33	18·7	14·4	48	58	21	17
	39–40	99	106	56	46	36	30	0·90	1·00	1·07	1·34	2·45	3·42	1·57	1·46	21·9	13·5	29	59	33	15
4463	36–37	118	135	59	56	33	29	0·97	1·07	1·64	1·37	4·05	3·72	1·70	1·47	14·5	15·1	65	59	12	12
	37–38	126	122	76	63	38	34	0·95	1·00	1·57	1·46	3·71	3·55	1·74	1·53	20·2	17·0	56	65	16	14
	38–39	134	134	71	58	34	30	0·95	1·04	1·61	1·32	3·89	3·48	1·76	1·37	18·3	16·7	58	66	15	13
	39–40	123	121	68	50	36	29	0·94	1·03	1·63	1·46	3·89	3·84	1·94	1·50	17·5	13·0	45	64	17	9
4466	36–37	116	131	58	54	33	28	0·97	1·08	1·50	1·40	3·70	3·86	1·55	1·43	15·7	14·1	67	66	13	11
	37–38	122	125	65	56	35	31	0·92	0·97	1·50	1·39	3·54	3·44	1·67	1·59	18·4	16·0	56	57	16	19
	38–39	130	141	65	56	33	29	0·90	0·99	1·62	1·47	3·69	3·70	1·72	1·56	17·6	15·1	62	61	13	13
	39–40	127	138	68	54	35	28	0·91	0·98	1·51	1·40	3·48	3·48	1·67	1·56	18·9	15·5	41	53	20	14

*Co. = Coimbatore Sri. = Srivilliputhur

TABLE IX

Mean weekly relative humidity (per cent) and temperature (°F.)

No. of weeks after sowing	Relative humidity								Temperature							
	Coimbatore (September to April)				Srivilliputhur (March to August)				Coimbatore (September to April)				Srivilliputhur (March to August)			
	1937-38	1938-39	1939-40	Mean	1938	1939	1940	Mean	1937-38	1938-39	1939-40	Mean	1938	1939	1940	Mean
1	73·0	72·4		72·7	68·1			68·1	77·1	80·2		78·6	87·3			87·3
2	63·4	68·1	70·8	67·3	67·5		69·7	68·6	79·1	80·7	76·8	78·9	87·5		82·2	84·8
3	66·7	79·7	70·6	72·1	70·4		62·8	66·6	79·0	77·5	80·8	79·1	86·4		84·9	85·6
4	67·3	70·2	66·0	67·7	73·6	51·8	68·2	64·7	79·0	78·5	80·4	79·3	88·4	86·8	83·6	86·3
5	81·9	69·8	70·8	74·2	70·4	60·9	55·6	62·2	75·5	79·3	80·2	78·3	87·3	86·4	85·4	86·4
6	74·6	67·3	77·8	73·4	70·9	64·6	68·3	68·0	76·4	78·8	79·6	78·3	91·2	85·0	83·8	86·7
7	71·3	67·7	77·4	72·0	66·3	...	68·9	67·4	77·3	81·1	79·5	79·3	90·6	...	84·8	87·7
8	68·2	76·0	80·4	74·8	65·1	72·3	74·8	71·7	77·3	77·8	78·3	77·8	90·9	84·0	79·9	84·9
9	80·1	77·2	77·8	78·3	68·3	71·7	77·3	72·3	76·5	75·8	79·7	77·3	91·7	88·7	80·8	87·1
10	81·3	70·8	83·5	78·8	70·2	72·8	71·2	71·3	73·2	77·1	77·3	75·9	88·4	86·3	84·2	86·3
11	79·1	62·8	81·8	74·5	64·4	57·5	66·4	62·6	75·5	77·5	78·3	77·1	86·4	89·8	84·6	86·9
12	82·7	67·7	84·8	78·5	63·6	60·7	63·0	62·6	74·2	76·7	76·8	75·9	86·3	90·3	86·6	87·7
13	80·8	66·3	74·7	74·0	66·8	61·9	59·9	62·9	73·1	77·7	77·0	75·9	86·8	89·4	87·8	88·0
14	70·2	69·0	72·0	70·3	67·0	60·7	66·0	64·6	72·6	75·8	76·5	74·9	83·4	86·8	87·3	85·8
15	69·3	65·5	67·3	67·3	63·0	62·8	73·1	66·3	70·9	76·7	75·2	74·3	84·2	86·7	84·7	85·2
16	68·2	64·8	68·1	67·0	77·2	55·3	61·7	64·7	74·1	75·2	75·2	74·8	84·8	88·6	85·3	86·2
17	68·3	74·0	64·3	68·8	80·4	61·3	57·8	66·4	75·3	73·2	75·1	74·5	85·9	86·4	83·9	85·4
18	63·1	56·6	62·7	60·8	64·3	58·3	63·3	61·9	72·8	73·5	72·8	73·0	82·6	87·6	84·8	85·0
19	66·8	74·8	64·3	68·7	77·6	58·7	63·7	64·1	74·9	75·2	75·5	75·2	81·5	87·2	83·5	84·1
20	63·2	68·6	63·8	65·1	66·0	57·8	65·7	63·2	74·3	73·8	74·2	74·1	85·5	88·8	83·0	85·7
21	59·3	65·4	59·6	61·3		60·5	62·9	61·7	74·2	75·2	71·8	73·7	82·6	90·3	83·8	85·6
22	60·2	57·5	61·7	59·7		62·1	59·7	60·9	75·7	76·7	75·6	76·0	83·9	89·2	84·8	86·0
23	70·0	54·8	61·3	62·0		74·3	64·7	69·5	78·1	76·7	76·7	77·2		83·7	81·8	82·8
24	70·0	60·2	60·3	63·5		62·7	66·3	64·5	79·2	78·5	78·7	78·8		86·5	81·3	83·9
25	62·1	54·8	56·7	57·8					78·4	81·0	79·0	79·5				
26	57·0	49·9	51·5	53·1					80·3	80·2	79·9	80·1				
27	58·2	56·5	50·7	55·1					82·7	83·0	79·6	81·8				
28	52·1	68·0	58·2	59·4					83·1	81·6	80·0	81·6				
29	60·2	59·4	59·2	59·5					80·3	81·9	81·2	81·1				
30	67·1	52·8	57·7	59·2					82·7	82·7	81·7	82·4				
31		64·5	53·8	59·2						84·8	83·2	84·0				

two factors is important in view of the fact mentioned by Stiles [1936]—'marked response to changes in temperature has been observed with a few plants, but in general, temperature appears to play a much smaller part as a stimulus than light and gravity'. But absence of facilities stands in the way of this enquiry.

Conclusion

The following points are revealed by the present study :

(1) At Srivilliputhur the fibres are longer, finer, more mature but lesser in number on the seed than at Coimbatore.

(2) The maturation period of the boll and the lengthening and thickening phases of the fibre are less at Srivilliputhur.

(3) The rate of length development and that of the secondary wall deposit are higher at this place.

(4) The improved length and fineness of the fibres and the reduction in their numbers per seed at Srivilliputhur appear to be caused by the higher temperature and solar radiation at this place.

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Appendix

The longitudinal section of a seed is more or less like the figure A, B, C, D (Fig. 4). As a first approximation the curved lines AB and AD may be replaced by straight lines AB and AD respectively. The perimeter then becomes the two sides of an isosceles triangle ABD plus the semi-circumference BCD. The surface of the seed is the surface of rotation when ABC revolves

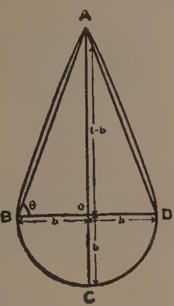

Fig. 4

round the axis AC; that is, the slanting face of a cone with base of diameter BD and slant height AB plus semispherical surface of diameter BD. If $2b$ is the breadth of the ovule, BD, and θ the angle ABD the surface area of the seed may be expressed as $\pi b.\, b \sec\theta + 2\pi b^2$

$$= \pi b\,(b \sec\theta + 2b) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If l is the length of the ovule, AC, then

$$\sec\theta = \frac{\sqrt{(l-b)^2 + b^2}}{b}$$

so that (1) becomes $= \pi b \left\{ \sqrt{(l-b)^2 + b^2} + 2b \right\} \ldots$ (2)

The perimeter of the section is 2 AB + semi-circumference BCD $= 2b \sec\theta + \pi b$

$$= 2\sqrt{(l-b)^2 + b^2} + \pi b$$

If we assume this section to have a thickness of d, equal to the diameter of a fibre of that section, then the surface area of the seed on which the fibres sprout will be given by $d \left\{ 2\sqrt{(l-b)^2 + b^2} + \pi b \right\} \ldots\ldots\ldots$ (3)

The number of fibres produced on this section as counted may be called n. Then the total number on the whole surface of the seed becomes from,

$$\text{(2) and (3)} = \frac{\pi b \left\{ \sqrt{(l-b)^2 + b^2} + 2b \right\}}{d \left\{ 2\sqrt{(l-b)^2 + b^2} + \pi \right\}}\, n \ldots\ldots (4)$$

RESEARCH NOTE

A PRELIMINARY NOTE ON THE USE OF SOME COMMON INDIAN FRUITS AND VEGETABLES IN MAKING JELLIES

By P. G. Krishna, Ph.D., Agricultural Chemist, Hyderabad, Deccan

(Received for publication on 9 June 1943)

Around Hyderabad city it has been a common practice for some decades of making jellies from guavas and wood apple. In making jelly with guavas four to six tablespoons of lemon juice is added to each quart of extracted juice from mature but not fully ripe guavas while the wood apple jelly is made without the addition of lemon juice.

For the past two years some work in the use of custard apple fruit in making jams and jellies has been in progress and during this time other common fruits and vegetables have also been investigated in this connection. It was found that many common fruits and vegetables are better suited for jellying being richer in pectin content than the custard apple fruit.

As a result of the work that has been done so far it might be stated that unripe but mature mango, wood apple and ***ambada*** (***Hibiscus cannabinus***) (red and white variety) form very satisfactory material for making jellies, being quite rich in both pectin and acid. The jellies are clear and have varying sparkling colours which keep well over several months. Guavas, ***ber***, ***ballar***, etc. make satisfactory jellies with the addition of required acid and have attractive colours and also keep well. But in the case of those requiring acid, the fruit flavour is usually not quite prominent as the lemon juice added gives the lemon taste and flavour.

Tamarind seed, ***ber*** seed and some millets also have considerable amounts of pectin but jellying even with the required acid is not satisfactory. Investigations with these and other fruits and vegetables are in progress.

PLANT QUARANTINE NOTIFICATION

Notification No. F. 16-5 (1)/43-A., dated 10th May 1943 of the Government of India in the Department of Education, Health and Lands.

In exercise of the powers conferred by sub-section (1) of section 3 of the Destructive Insects and Pests Act, 1914 (II of 1914), the Central Government is pleased to make the following order for the purpose of prohibiting, regulating and restricting the import of live fungi into British India ;

1. In this order, 'fungus' means any living fungus in culture media or on living plants or any fungus spores or mycelium intended to be so cultured, but excludes dried specimens not intended to be so used.

2. No fungus shall be imported into British India unless—

(*a*) it is consigned to the Imperial Mycologist, Imperial Agricultural Research Institute, New Delhi, or

(*b*) it is accompanied by a special permit, in accordance with the form set forth in the Schedule to this order, authorizing such importation issued by the Imperial Mycologist :

Provided that a permit shall not be refused in respect of any fungus which is not, in the opinion of the Imperial Mycologist, likely to cause infection to any crop.

3. This order shall come into force with effect from 1 September 1943.

SCHEDULE.

Form of special permit authorizing importation of living fungi in pure culture.

1. Name, designation, and full address of the importer ....
2. Name of the fungus to be imported........
3. Country from which importation is sought...............................
4. Whether importation is intended by sea, land or air..........................
5. Whether in its original home the fungus is a parasite, and if so, the name of the host plant..........................
6. Name, designation and address of the exporter............................
7. Purpose of importation ....

The above information is true to the best of belief.

Date........... (Signature of the importer).

I authorize the importation. This permit will be valid up to....................................

Date............... (Signature of Imperial Mycologist).

[*N.B.*—The permit must be obtained in advance of sending the order. The tubes or other container of the fungus must be clearly and distinctly marked with the name of the fungus, which should agree with the name on the import permit].

ERRATUM

The Indian Journal of Agricultural Science,

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Page 321, column 1, line 16, *for* '15 April 1943' *read* '15 May 1943'.

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